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COLIFORM BACTERIA GROWTH AND CONTROL IN AERATED STABILIZATION BASINS

S. H. Watkins

Crown Zellerbach Corporation

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Secondary effluent from an ammonia base sulfite mill in Lebanon, Oregon, increased concentrations of coliforms (total coliform bacteria) in receiving waters to more than 1000 per 100 ml, the State standard. Factors responsible for high coliform populations were determined and a disinfection method was developed for reducing their numbers in secondary effluent. Chlorination was often ineffective. However, by injecting NaOH into the chlorinator's water supply, adequate coliform kill was achieved with approximately 5.7 ppm chlorine and 3.3 ppm NaOH. Continuous chlorination affected a reduction in coliforms in receiving waters to acceptable levels and the chlorinated effluent had a low degree of toxicity to salmonid fingerlings. (EPA)

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COLIFORM BACTERIA GROWTH AND CONTROL IN AERATED STABILIZATION BASINS

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Program Element 1BB037

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ABSTRACT

The State of Oregon has a standard of 1000 coliform bacteria (coliforms) per 100 ml for recreational waters. Secondary effluent from a sulfite mill in Lebanon, Oregon, consistently had the potential to increase the coliform population in the South Santiam River to concentrations greater than 1000 per 100 ml. This provided an opportunity to determine factors responsible for high coliform levels in an industrial waste and to develop methods for reducing their numbers. The high concentrations of coliforms in Lebanon effluent were not due to their growth during secondary treatment but rather reflected development at earlier stages. In a small scale system, coliforms were reduced to acceptable levels in a secondary treatment unit by killing them in the incoming wastes. Methods for accomplishing this on a full scale were not found, therefore disinfection was investigated as an alternative. A modified chlorination system which employed caustic injection into the chlorinator's water supply was the most effective treatment tested. The ability of the process to reduce coliforms to acceptable levels in the South Santiam River was demonstrated. Chemical analyses and fish bioassays showed that the process would not contribute toxic chlorine residuals to the receiving waters. Rapid methods for estimating colicidal activity are described. Factors which affect coliform populations in mill systems and those which affect chlorine activity are discussed.

This report was submitted in fulfillment of Project Number 12040 GQD by Crown Zellerbach Corporation under the partial sponsorship of the Environmental Protection Agency. Work was completed as of November 31, 1972.

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SECTION I

CONCLUSIONS

1. Both the Multiple Fermentation Tube (MT) and Membrane Filter (MF) methods are satisfactory procedures for the study of coliform growth and the dynamics of disinfection. The latter procedure is preferable because it is more precise and requires less time and equipment.

2. Compared to the MF method, the MT procedure gives somewhat higher values for coliform concentrations in chlorinated and unchlorinated secondary effluent. If coliform data is relevant to pollution abatement standards, the MT technique should be used or the suitability of alternate methods should be established.

3. Without further treatment, secondary effluent from the Lebanon mill has the potential for consistently increasing coliform concentrations in the South Santiam River to more than 1000 per 100 ml. The mean coliform concentration of 107 effluent samples was 25 million per 100 ml.

4. Coliforms do not proliferate in the secondary ponds. Averaged over a 15 month period their concentrations were considerably greater in wastes before secondary treatment.

5. Conditions which are conducive to coliform growth include recycling of high BOD materials within the mill, extended storage within the mill and in primary treatment, and the accumulation of sediments. Coliforms in the raw water supply are a continuous source of inoculum.

6. Coliforms are not necessary for the secondary treatment of sulfite mill wastes. In effluent from the aerated basins they represented less than 2 percent of the total bacterial population and in a small scale system good BOD reduction was achieved when coliforms were less than 0.0005 percent of the total bacteria.

7. The most important factor which influences coliform concentrations in secondary effluent is the number of coliforms added to the aeration basins, i.e. inoculation. Changes in coliform populations in secondary effluent reflected those which occurred in the influent. In a small scale aeration unit coliform concentrations were reduced by more than 99 percent by killing coliforms in the influent.

8. Pretreatment to kill coliforms may be a practical way to obtain secondary effluents with acceptable levels of coliforms. Methods could include heating and selective chlorination of wastes within the mill. In experiments with small scale equipment, acidification of secondary influent, followed by neutralization, was a successful treatment. Coliform concentrations in the waste after secondary treatment were as low as 1400 per 100 ml. The lowest value found for a control unit was 1.2 million per 100 ml.

9. Coliforms in secondary effluent from ammonia base sulfite processes can be reduced to acceptable levels by approximately 5 ppm chlorine, added as hypochlorous acid (HOCl) or sodium hypochlorite (NaOCl). Molecular (gaseous) chlorine is not a suitable bacteriocide.

10. The most important factor which influences the activity of chlorine against coliforms in Lebanon effluent is the pH of the chlorinating solution. Chlorinating solutions with pHs of about 2 are relatively ineffective. At higher pHs greater concentrations of total residual chlorine are obtained without increasing the chlorine application rate. This correlates with increased bactericidal activity.

11. The effect of chlorinating solution pH on bactericidal activity is related to one or more of the following reactions occurring near the chlorine-effluent interface, before complete mixing:

a. Equilibrium reactions involving chlorine.

b. Ionization of lignosulfonic acids and/or ammonia.

c. Formation of monochloramine (NH_2Cl).

Low pH favors reactions between molecular chlorine and unionized lignosulfonic acids which inactivate chlorine. At pH 7 and higher, HOCl and hypochlorite ions (OCl^-) react more slowly with lignosulfonate ions and the formation of NH_2Cl becomes possible. Complete mixing may occur before active chlorine reacts with lignosulfonates.

12. Reaction rates between chlorine and effluent are related to the concentrations of reactants. When the concentration of chlorine in a chlorinating solution is increased the reaction rate with effluent also is increased. When gaseous chlorine (Cl_2) is used there is an interrelationship with pH which may make it especially difficult to attain bactericidal chlorine residuals. With increasing levels of chlorine, solutions become more acidic. This lowers the pH of larger volumes of chlorine-effluent mixtures and reactions between Cl_2 and lignosulfonic acids become more complete before dilution can occur.

13. Sulfite ($SO_3^=$) reacts rapidly with active chlorine. Approximately 30 percent of the "Biological Chlorine Demand" of Lebanon secondary effluent was due to $SO_3^=$. Concentrations of $SO_3^=$ in other wastes were too high for adequate coliform kill with practical amounts of chlorine.

14. Full scale chlorination of secondary wastes from the ammonia base sulfite pulping process can be improved by injecting sodium hydroxide into the chlorinator's water supply. The amount required is that for the neutralization of HCl formed from chlorine hydrolysis. Put another way, it is the amount required to convert molecular chlorine to hypochlorous acid. With this system coliforms were killed by 5 ppm of applied chlorine. Without it, chlorine concentrations of 20 ppm were often ineffective.

15. A chlorination system which responds to changes in effluent flow would be more appropriate for the Lebanon operation. Variations in effluent flow rates caused fluctuations in the concentrations of applied chlorine because of a constant chlorine addition rate. Minor fluctuations were due to batch processing. Major changes were caused by variations in wind velocity and direction over the ponds.

16. Secondary effluent from both series and parallel operation can be treated effectively with approximately 5 ppm chlorine. However, when the mode of operation is changed from series to parallel, effective treatment cannot be achieved with practical levels of chlorine for at least several days. This is due to increased concentrations of sulfite in the first pond in series.

17. In this study it was found that the concentrations of chlorine required to accomplish the following correlated well with those required to reduce coliforms to acceptable levels:

a. Stop bacterial motility within 30 minutes.

b. Inhibit oxygen uptake by secondary effluent by 64 percent or more.

c. Provide a total chlorine residual after a contact time of 5 minutes (5 minute residual).

Three rapid methods for estimating chlorine activity were developed using these criteria. They proved very useful in determining the conditions required for effective chlorination and in monitoring full scale chlorination.

18. Chlorination procedures which reduce coliforms to acceptable concentrations do not produce effluents which would be toxic in receiving waters. This conclusion was based on the following observations:

a. Total chlorine residuals rarely persist for more than 2 hours in secondary effluent. Passage time to receiving waters is 4 to 6 hours.

b. The forms of chlorine which have a high degree of toxicity, hypochlorous acid and the chloramines, are not detectable 5 minutes after chlorination. Monochloramine added to secondary effluent to provide 10 ppm chlorine reacts completely within 10 minutes.

c. Chlorinated effluent, aged for 2 hours, was not toxic to salmonoid fingerlings when the waste was 20 times more concentrated than it would be in receiving waters.

19. Continuous full scale chlorination had a beneficial effect on the quality of receiving waters. Coliform concentrations in the South Santiam River 3 miles and 8 miles downstream from the mill discharge were reduced to the levels found upstream from the mill. Dissolved oxygen in chlorinated effluent was not depleted during passage to the river. This resulted in higher D.O. levels in the river particularly at the confluence of the effluent and the river. By neutralizing HCl from chlorine hydrolysis, the caustic injection procedure minimized pH changes which could affect receiving waters.

20. The chlorination procedure for the Lebanon mill requires 113 Kg/day (250#/day) of chlorine and 65 Kg/day (143#/day) of NaOH. Added to secondary effluent with an average flow of 19.7 million l/day (5.2 million gal./day) this would provide concentrations of 5.7 ppm chlorine and 3.3 ppm NaOH. At the time of writing chemical costs were 0.123 $/Kg (0.056 $/lb) for chlorine and 0.060 $/Kg (0.0272 $/lb) for NaOH. The daily cost for chemicals would be approximately $18. Of this total 22 percent was for NaOH.

21. The chlorination system described offers certain advantages. Chlorine gas and sodium hydroxide can be purchased in concentrated form and stored separately until needed. This avoids the high shipping costs associated with dilute germicidal solutions such as sodium hypochlorite. Since the two chemicals are not combined until a few seconds before use there is no problem with loss in activity due to storage. The procedure also provides a convenient means for comparing chlorination and hypochlorination processes with relatively little capital expense.

22. The modified chlorination system may have application for other types of wastes. However, if the formation of NH_2Cl is required for its success, wastes which are deficient in ammonia nitrogen would have to be supplemented with a source of ammonia ions.

SECTION II

RECOMMENDATIONS

1. The modified chlorination processes may have application to wastes other than those from sulfite mills and should be evaluated further. The main feature of the method is to increase the pH of chlorinating solutions before they contact the waste in order to reduce initial reaction rates. In this study there was little opportunity to optimize the process. Improvements might result from increasing the mixing time of caustic and water and/or that between chlorine and diluted caustic before the mixture reaches the waste to be treated. Ammonia would be a less expensive neutralizing agent but was not effective in this study perhaps because of inadequate retention time. These are areas which merit further attention.

2. Lebanon secondary effluent contains over 100 ppm NH_3 which suggests that chloramine formation may have contributed to the bactericidal acitvity found in chlorinated effluent. Although no chloramines could be detected within 5 minutes of chlorination, with normal amounts of chlorine, the question was not resolved completely. It would be pertinent to evaluate the bactericidal activity of Cl_2, HOCl and NaOCl added to lignosulfonate containing wastes with and without ammonia. Wastes from a sodium base or magnesium base sulfite process would be appropriate starting materials.

3. Experiments with small aeration units showed that coliform concentrations in secondary effluent could be dramatically reduced by

restricting their entry into the aeration units. This approach to coliform control should be studied for full scale processes. Treatment of coliform-containing wastes within the mill or changes in operating procedures to minimize retention time and accumulations of sediments are potential methods.

4. More information is needed on the reaction products of chlorine with various wastes. This becomes increasingly important as regulations require the disinfection of industrial effluents. Properties of interest include the chemical nature of the compounds, their stability and their toxicity to aquatic life. Attention should be given to the various forms of chlorine. It is possible that for one type of waste molecular chlorine would produce toxic addition products whereas sodium hypochlorite would form oxidation products of low toxicity.

5. A system has been devised for varying the rate of chlorine and caustic addition in response to changes in effluent flow. Optimum conditions for chlorination should be established with the new apparatus.

SECTION III

INTRODUCTION

Coliform bacteria, commonly known as coliforms, are present in large numbers in the intestinal tracts of warm blooded animals. They can be distinguished from other types of bacteria by their ability to ferment the milk sugar lactose. These two characteristics were largely responsible for establishing coliforms as indicators of human fecal pollution. Currently, 29 states use total coliform populations as an index of water quality and 24 of these, including Oregon, have a standard of 1000 total coliforms per 100 ml for recreational waters.[1] High concentrations of coliforms in two Oregon rivers have been associated with industrial effluents.[2] The sanitary significance of coliforms in industrial wastes is a debatable subject and outside the scope of this study. Less controversial is the fact that a high background level of coliforms from industrial wastes makes it difficult to detect pollution from sources of known public health significance. This was the type of situation encountered with the Crown Zellerbach sulfite mill in Lebanon, Oregon. Coliform concentrations in secondary effluent from this mill were consistently great enough to cause an increase in coliforms in receiving waters, the South Santiam River, to more than 1000 per 100 ml. This complicated sanitary surveys but also provided the opportunity to determine the reasons for high concentrations of coliforms in an industrial waste and to develop methods for reducing their numbers to acceptable levels.

SECTION IV

APPARATUS AND METHODS

ENUMERATION OF BACTERIA

Total Bacteria

The Standard Plate Count procedure described in Standard Methods for the Examination of Water and Wastewater (Standard Methods)[3] was used except that plates were incubated at 20 to 25° C. for 4 to 6 days rather than the conditions specified. Prior to plating, chlorinated samples were treated with sodium thiosulfate to inactivate any residual chlorine.

Coliforms

Multiple Tube (MT) -- The Presumptive Test[3] was used to enumerate total coliforms. Five Lactose Broth (Difco) fermentation tubes were used for each sample dilution tested. Concentrations of coliforms were computed from Most Probable Number (MPN) tables.[3]

Membrane Filter (MF) -- The Standard Total Coliform Membrane Filter Procedure[3] was used with m-Endo Broth-MF (Difco).

Chlorinated samples were treated with sodium thiosulfate before analyzing.

MILL PRODUCTION AND WASTE TREATMENT

Production

The facilities at Lebanon, Oregon include an ammonia base sulfite mill which produces unbleached paper products and lignosulfonate containing by-products. The mill operates 3 batch digesters which produce 9 to 10 cooks every 24 hours.

Waste Treatment

Spent Sulfite Cooking Liquor -- Strong liquor is evaporated to a 40 to 50 percent solids concentration. It may be processed further in the manufacture of by-products or burned if the supply exceeds the demand. Weaker spent sulfite liquor is recycled while very dilute liquor goes to primary treatment.

Primary Treatment -- Combined mill waste which includes paper machine effluent, dilute spent sulfite liquor and by-product evaporator condensate is pumped over a side hill screen for fiber recovery and into a primary settling pond. Total liquid flow is approximately 17.4 million l/day (4.6 MGD). Because of batch pulping and variations in by-product manufacture, the volume and composition of the waste fluctuate. The primary pond provides a retention time of 2 to 8 hours depending on the accumulation of sediment. Periodically, the primary is pumped and the solids are disposed of as landfill. During this operation which takes 4 to 5 days, unscreened, unsettled waste goes directly to the secondary ponds. During the 6 to 8 hours required to refill the primary pond there is no flow to the secondary units.

Secondary Treatment -- Wastes going to secondary treatment are supplemented with 1 to 1.5 ppm phosphorus and adjusted to pH 7 with ammonia, when necessary. The two secondary ponds have a capacity of 64 million l (17 million gal.) each and provide a retention time of approximately

7 days. During this study pond 1 contained six 25 hp aerators and one 75 hp aerator. Pond 2 was operated with two 75 hp units. Secondary effluent is discharged into Mark Slough which flows into the South Santiam River. Residence time in the slough is 4 to 6 hours. Dilution of secondary effluent in the South Santiam River is in the range of 1:80 to 1:280 during periods of low flow.

Additional information on waste treatment has been given by Amberg, et. al.[12]

SMALL SCALE WASTE TREATMENT

Equipment

The function and capacities of components of the small waste treatment system (Figure 12) are given in Table 11. Units 2 through 8 were plastic containers purchased locally. Cork borers were used to make the correct size holes for snug fits of tubing and stoppers which were used to interconnect the units. The aeration stages, 9 and 10, were plastic lined, 208 l (55 gal.) metal drums. The contents of these units were temperature controlled and completely mixed by recirculation through the drums and through heating chambers fitted with 2000 watt, thermostatically controlled, immersion heaters. Jabsco pumps connected to adjustable Vickers drive units were used for recirculation. Aeration was accomplished by aspirating air into the recirculation lines on the vacuum sides of the pumps. A multichannel peristaltic metering pump was used to dispense H_2SO_4 and NaOH solutions and for pumping settled influent to the aeration units.

Flow Sequence and Control

In the following description, numbers in parentheses refer to the units shown in Figure 12. Neutralized influent from the mill manifold was gravity fed through a 5.2 cm (2 in.) plastic line (1) to a constant level headbox (2). Excess influent was sewered. Flow from the headbox was adjusted to 1.5 l/min by rotating an adjustable delivery tube to the correct angle. In this system the vertical distance between the surface of the influent in the constant level headbox and that in the delivery tubes represents the effective head. By rotating the tube the effective head can be varied with a corresponding change in flow rate. The waste basket (3) directed influent into the bottom of a 5.2 cm plastic pipe which was installed in the first settling stage (4). This reduced turbulence for more effective settling. The settled influent flowed by gravity from the near top of unit 4 to the bottom of the second settling stage (5).

The discharge from unit 5 was divided. A small amount, 32 ml/min was pumped to the control aeration unit (10). The balance of 1.47 l/min was gravity fed to a stainless steel T in the acidification unit (6). Five percent H_2SO_4 was pumped into another leg of the T at 28 ml/min. The acid was carried in 0.32 cm (1/8 in.) tygon tubing which extended into the influent stream to prevent direct contact between acid and the metal T. Again, by gravity flow, acidified influent went to the bottom of a retention stage (7) to increase the exposure time of bacteria to low pH influent. From the near top of this stage the waste flowed to the bottom of unit 8 where it was neutralized with 4.1 percent NaOH in the same manner as described for acidification. Finally from the upper section of unit 8 neutralized influent was pumped to the experimental aeration drum (9) at the rate of 32 ml/min. The rest of the neutralized influent was sewered.

Monitoring

Daily, or more frequently, pH measurements were made on waste in units 6 and 7 to determine if acidification was adequate. Checks also were made on the equivalence of reagents. To do this both NaOH and H_2SO_4 reagents were pumped at normal rates for 1 minute into 1.51 of influent.

If the pHs of influent before and after reagent addition were not the same, appropriate adjustments were made of caustic flow rate.

Start Up Procedure

Unit 8, the neutralization stage, was filled with influent from the mill manifold. The two aeration units, 9 and 10, were filled with unchlorinated secondary effluent and connected to earlier stages via the peristaltic pump (11). The system then was put into operation.

ANALYTICAL METHODS

Unless noted otherwise, procedures were those described in Standard Methods.[3]

Total Residual Chlorine

To 100 ml sample volumes were added an excess of potassium iodide, approximately 1 ml of 20 percent H_2SO_4 and 1 to 2 ml of a 0.5 percent starch solution. The blue starch-iodine complex was titrated to a colorless end point with 0.025 N sodium thiosulfate. Preliminary tests showed that acetic acid and H_2SO_4 gave the same values for total residual chlorine in effluent treated with sodium hypochlorite. Sulfuric acid was used for future tests because its lower volatility made it less objectionable to work with, especially in field studies.

Dissolved Oxygen

All dissolved oxygen measurements were made with a Yellow Springs Instrument Co. (YSI) Model 54 Oxygen Meter. Oxygen uptake studies were made using Model 5420 self-stirring BOD Bottle Probe. All other measurements were made with a standard probe.

SAMPLING

All samples were grab samples which were analyzed within 2 hours. Those for bacteriological analyses were collected in sterile, plastic Whirl-Pak (Nasco) bags.

FISH TOXICITY STUDIES

Apparatus (Figures 46 and 47)

The aging box, headboxes and fish channels were 1.9 cm (3/4 in.) plywood painted with 3 coats of Fish Hatchery White paint. The fish channels and water headbox had been used in previous studies.[12] The aging box channels were 28.7 cm wide and 81.3 cm high (11.3 in. x 32 in.). This tall, narrow configuration suggested that uneven heating or other factors might cause large variations in flow rates between upper and lower portions of effluent. To evaluate this the box was first filled with water. Water was then continuously pumped into the mixing funnel at the same rate as planned for effluent. Enough brom cresol green dye was added to provide a distinct pattern. During passage through the channels a wedge shaped pattern was formed with the bottom leading the top by 15 minutes after 2 hours. Temperature readings taken with a submersible probe showed the lower portions of effluent to be 0.2 to 0.3° C. colder than upper portions.

Flow Sequence and Control

Prior to full scale chlorination, secondary effluent was pumped to the mixing funnel at the rate of 26.5 l/min (7 gal./min). A sodium hypochlorite stock solution containing 10,000 ppm active chlorine was added to the effluent at the rate of 26.5 ml/min to provide an initial chlorine concentration of 10 ppm. Chlorine flow rate was controlled with an adjustable delivery tube as described for the small scale system. The solution was added from a Mariotte box. This was a closed container, fitted with an air inlet tube which extended into the chlorinating solution. The effective head for flow regulation was the vertical distance between the bottom of the air inlet tube and the tip of the delivery tube. This made it possible to use most of the chlorinating solution without changing the effective head pressure. When full scale mill chlorination was started, mill chlorinated effluent was pumped to the funnel.

From the Mix Box chlorinated effluent flowed by gravity to the Effluent Delivery Box. Excess flows were used to provide a constant head at this stage. Flow to the Aging Box was regulated by adjusting three delivery tubes. Depending on the retention time desired, a pump was positioned in the Aging Box and aged effluent was pumped to the Effluent Head Box at an excess rate to provide a constant head. Flow of chlorinated effluent to the channels was controlled with adjustable delivery tubes. To obtain controls, unchlorinated effluent was pumped at the desired rate to the top of the mixing flume of one of the fish channels. Desired flow rates of dilution water to the channels were obtained by adjusting v-notch weirs in the Water Head Box.

Handling of Fish

Steelhead trout (*Salmo gairdneri*) and Sockeye salmon (*Oncorhynchus nerka*) fingerlings were obtained from the Fish Toxicological Station of the Environmental Protection Agency in Corvallis, Oregon. They were transported to the test site in oxygenated carboys. The fish were maintained in a channel with flowing water for at least 5 days. The required numbers were then transferred to test channels which contained water flowing at the standardized rate of 0.63 l/sec (10 gal./min). At this stage the Effluent Head Box contained only water which was being added to the channels at rates equivalent to those to be used for chlorinated effluent. After an additional 3 days for acclimatization, water flow to the Effluent Head Box was replaced by an equivalent flow of chlorinated and aged effluent.

SECTION V

EVALUATION OF METHODS FOR ENUMERATING COLIFORMS

COMPARISON OF MF AND MT TESTS

The current edition of Standard Methods[3] recognizes two standard procedures for enumerating coliforms. They are the Membrane Filter (MF) procedure, and the use of Multiple Fermentation Tubes (MT) to determine the most probable numbers. These two techniques were used to determine coliform concentrations in various mill wastes.

For 10 out of 14 samples of unchlorinated wastes the MT procedure yielded higher results (Table 1). However, on the basis of $\log_{10}$ of coliform concentrations, differences were minor (Figure 1) with maximum variations being approximately 0.5 $\log_{10}$ unit. Because of the enormous numbers required to express bacterial populations and differences in concentrations, it is common practice to express them in log units.

The MT procedure also gave higher coliform counts for 25 out of 32 samples of chlorinated secondary effluent (Table 2). However, when the $\log_{10}$ of coliforms were plotted against chlorine concentrations or reaction times (Figures 2-5), similar death curves were obtained using data obtained by the two procedures.

For the following reasons the MF procedure was used to enumerate coliforms in most of the subsequent studies:

Table 1. COMPARISON OF MEMBRANE FILTER AND MULTIPLE TUBE METHODS FOR ENUMERATING COLIFORMS IN UNCHLORINATED MILL WASTES

Description of samples			Coliform bacteria				Diff. between methods, %	Method giving highest count
			Cells/100 ml		Log_{10} cells/100 ml			
Date	Source	pH	Membrane filter	Multiple tube	Membrane filter	Multiple tube		
9/16/71	Primary influent	3.80	39×10^2	49×10^2	3.59	3.69	23	Tube
9/22/71	Secondary effluent	6.70	31×10^5	70×10^5	6.49	6.85	77	Tube
9/23/71	Secondary effluent	6.90	48×10^5	79×10^5	6.68	6.90	49	Tube
9/24/71	Secondary effluent	--	53×10^5	54×10^5	6.72	6.73	2	Tube
9/28/71	Secondary effluent	7.05	33×10^5	46×10^5	6.52	6.66	33	Tube
9/28/71	Main sewer before evaporator	9.15	17×10^4	23×10^4	5.23	5.36	30	Tube
9/28/71	Main sewer water leg after evaporator	8.65	60×10^4	49×10^4	5.78	5.69	20	M.F.
9/29/71	Secondary effluent	7.15	49×10^5	170×10^5	6.69	7.23	110	Tube
10/26/71	Secondary effluent	7.20	320×10^5	350×10^5	7.51	7.54	9	Tube
10/27/71	Secondary effluent	7.30	240×10^5	130×10^5	7.38	7.11	59	M.F.
3/16/72	Secondary effluent	7.20	200×10^5	140×10^5	7.30	7.15	35	M.F.
3/17/72	Secondary effluent	7.20	250×10^5	130×10^5	7.40	7.11	63	M.F.
4/4/72	Secondary effluent	6.90	130×10^6	160×10^6	8.11	8.21	21	Tube
4/12/72	Secondary effluent	7.45	90×10^5	350×10^5	7.95	7.54	118	Tube

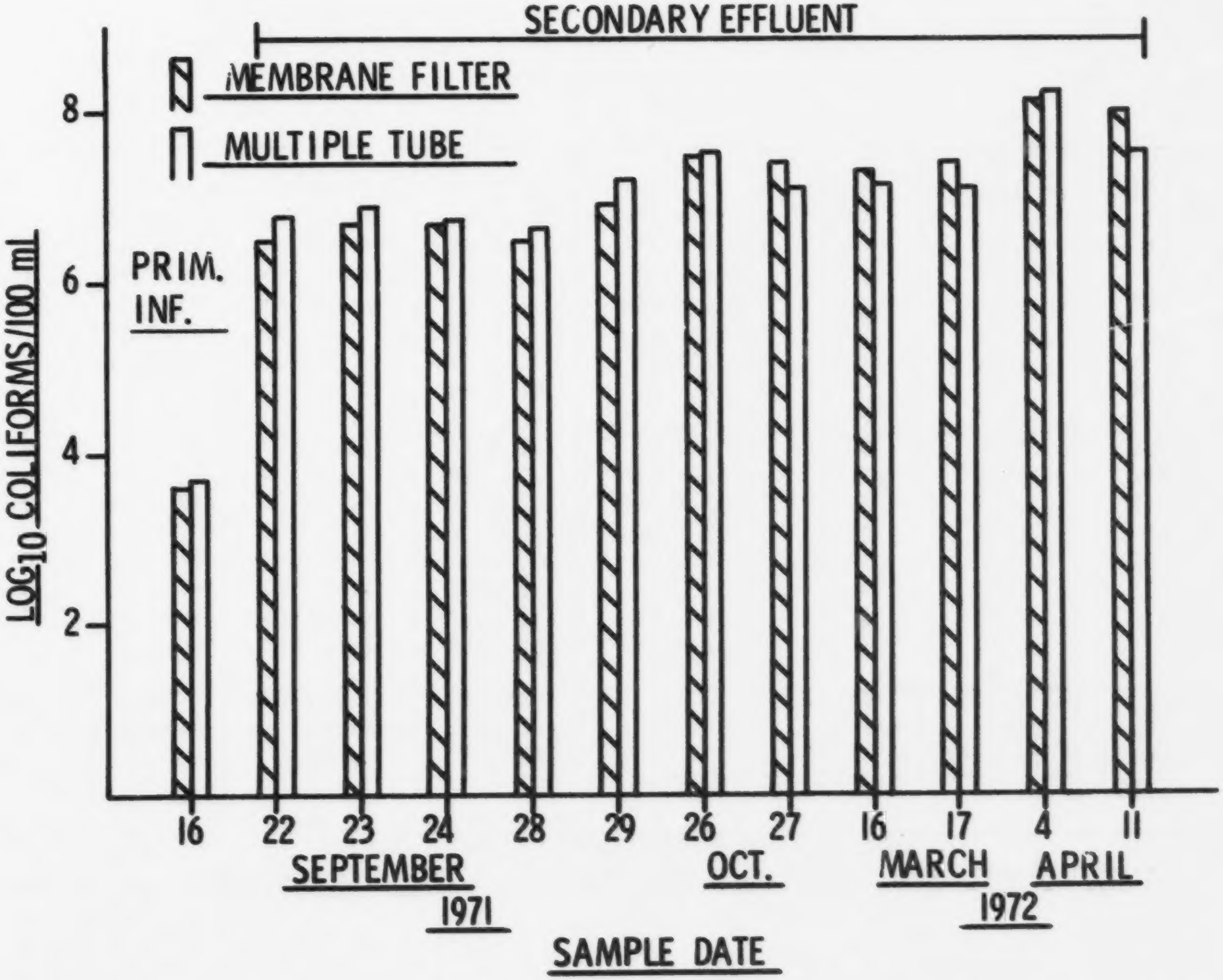


Figure I. Comparison of methods for enumerating coliforms in unchlorinated mill wastes.

Table 2. COMPARISON OF MEMBRANE FILTER AND MULTIPLE TUBE METHODS FOR ENUMERATING COLIFORMS IN CHLORINATED SECONDARY EFFLUENT

Date (1971)	Cl conc., ppm	Reaction time	Method of chlorine application	Coliform bacteria				Diff. between methods, %	Method giving highest count
				Cells/100 ml		Log_{10} cells/100 ml			
				Membrane filter	Multiple tube	Membrane filter	Multiple tube		
9/22	1.0	10 Mins.	Cl_2-Mill	29×10^5	49×10^5	6.46	6.69	51	Tube
9/24	2.3	10 Mins.	Cl_2-Mill	51×10^5	54×10^5	6.71	6.73	6	Tube
9/28	7.0	10 Mins.	Cl_2-Mill	29×10^2	80×10^2	3.46	3.66	94	Tube
9/28	7.0	20 Mins.	Cl_2-Mill	4×10^2	20×10^2	2.60	3.30	133	Tube
9/29	5.3	10 Mins.	Cl_2-Mill	21×10^5	54×10^5	6.32	6.51	88	Tube
9/29	7.0	10 Mins.	Cl_2-Mill	74×10^4	350×10^4	5.87	6.54	130	Tube
9/29	8.9	10 Mins.	Cl_2-Mill	81×10^3	920×10^3	4.91	5.96	168	Tube
9/29	10.8	10 Mins.	Cl_2-Mill	1×10^2	35×10^2	2.00	3.54	189	Tube
10/26	9.1	1 Min.	Cl_2-Mill	22×10^5	1300×10^5	6.34	8.11	193	Tube
10/26	9.1	5 Mins.	Cl_2-Mill	39×10^4	170×10^4	5.59	6.75	125	Tube
10/26	9.1	10 Mins.	Cl_2-Mill	12×10^4	92×10^4	5.08	5.71	154	Tube
10/26	9.1	20 Mins.	Cl_2-Mill	32×10^3	79×10^3	4.51	4.65	85	Tube
10/26	9.1	40 Mins.	Cl_2-Mill	37×10^2	350×10^2	3.57	4.54	162	Tube
10/26	9.1	80 Mins.	Cl_2-Mill	8×10^2	18×10^2	2.90	3.26	77	Tube
10/26	9.1	160 Mins.	Cl_2-Mill	11×10^2	17×10^2	3.04	3.48	43	Tube
10/26	9.1	320 Mins.	Cl_2-Mill	61×10^1	28×10^1	2.79	2.45	74	M.F.
10/26	9.1	24 Hours	Cl_2-Mill	63×10^1	5	2.80	0.70	197	M.F.

Table 2 (continued). COMPARISON OF MEMBRANE FILTER AND MULTIPLE TUBE METHODS FOR ENUMERATING COLIFORMS IN CHLORINATED SECONDARY EFFLUENT

Date (1972)	Cl conc., ppm	Reaction time	Method of chlorine application	Coliform bacteria				Diff. between methods, %	Method giving highest count
				Cells/100 ml		Log_{10} cells/100 ml			
				Membrane filter	Multiple tube	Membrane filter	Multiple tube		
3/16	8.0	30 Mins.	NaOCl-Lab	9×10^2	14×10^2	2.96	3.15	43	Tube
	10.0	30 Mins.	NaOCl-Lab	38×10^2	21×10^2	3.58	3.32	58	M.F.
	10.0	30 Mins.	Cl_2-Mill	10×10^6	8×10^6	7.00	6.90	22	M.F.
	12.5	30 Mins.	Cl_2-Mill	6×10^6	9×10^6	6.78	6.96	40	Tube
	12.8	30 Mins.	Cl_2-Mill	9×10^6	5×10^6	6.96	6.70	57	M.F.
	20.5	30 Mins.	Cl_2-Mill	3×10^6	54×10^6	6.48	7.73	179	Tube
	26.0	30 Mins.	Cl_2-Mill	37×10^2	17×10^4	3.57	5.23	191	Tube
3/17	4.0	30 Mins.	NaOCl-Lab	40×10^3	30×10^3	4.60	4.48	29	M.F.
	6.0	30 Mins.	NaOCl-Lab	5×10^3	2×10^3	3.70	3.30	86	M.F.
	8.0	30 Mins.	NaOCl-Lab	3×10^4	17×10^4	4.48	5.23	140	Tube
	10.0	30 Mins.	NaOCl-Lab	5×10^4	2×10^3	4.70	3.30	185	M.F.
	21.2	30 Mins.	Cl_2-Mill	30×10^5	8×10^5	6.48	5.90	116	M.F.
	22.2	30 Mins.	Cl_2-Mill	77×10^4	170×10^4	5.89	6.23	75	Tube
4/12	10.0	6 Mins.	NaOCl-Lab	$< 10^2$	79×10^3	<2.00	4.90	199	Tube
	10.0	30 Mins.	NaOCl-Lab	1×10^2	13×10^2	2.00	3.11	171	Tube

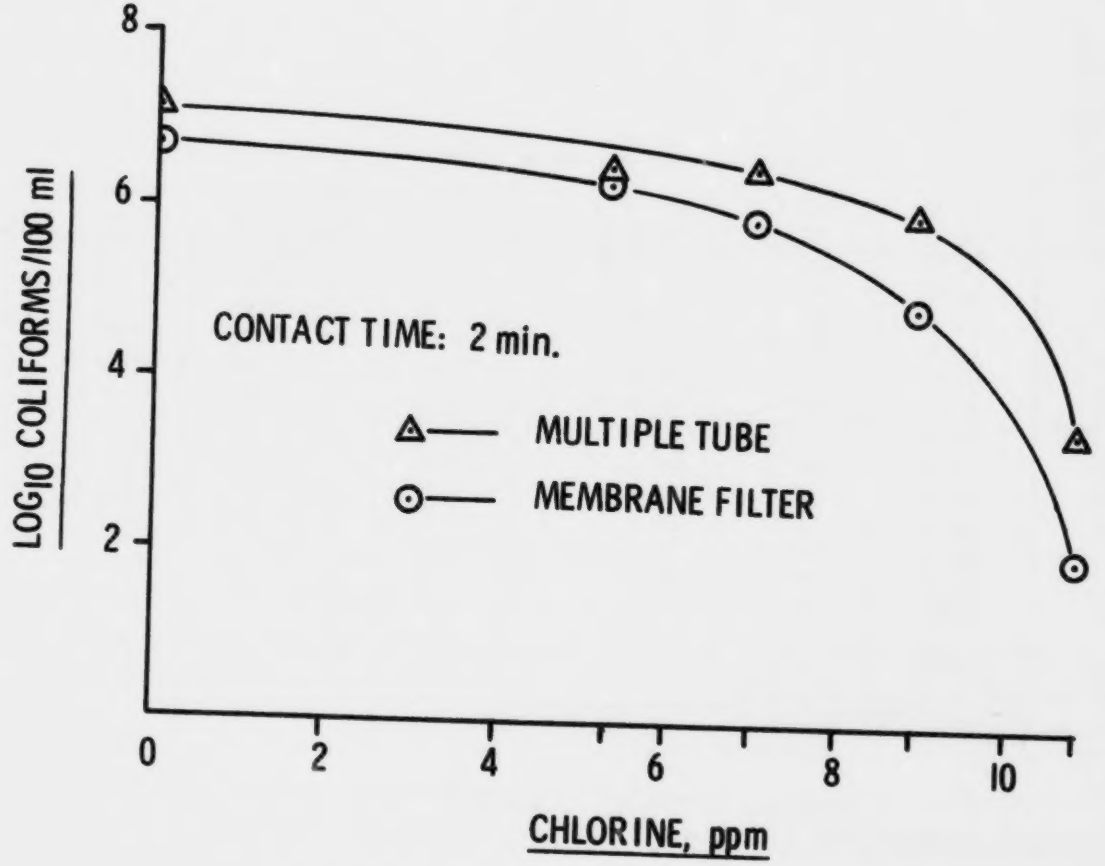


Figure 2. Comparison of methods for enumerating coliforms in chlorinated effluent. Mill trial of September 29, 1971

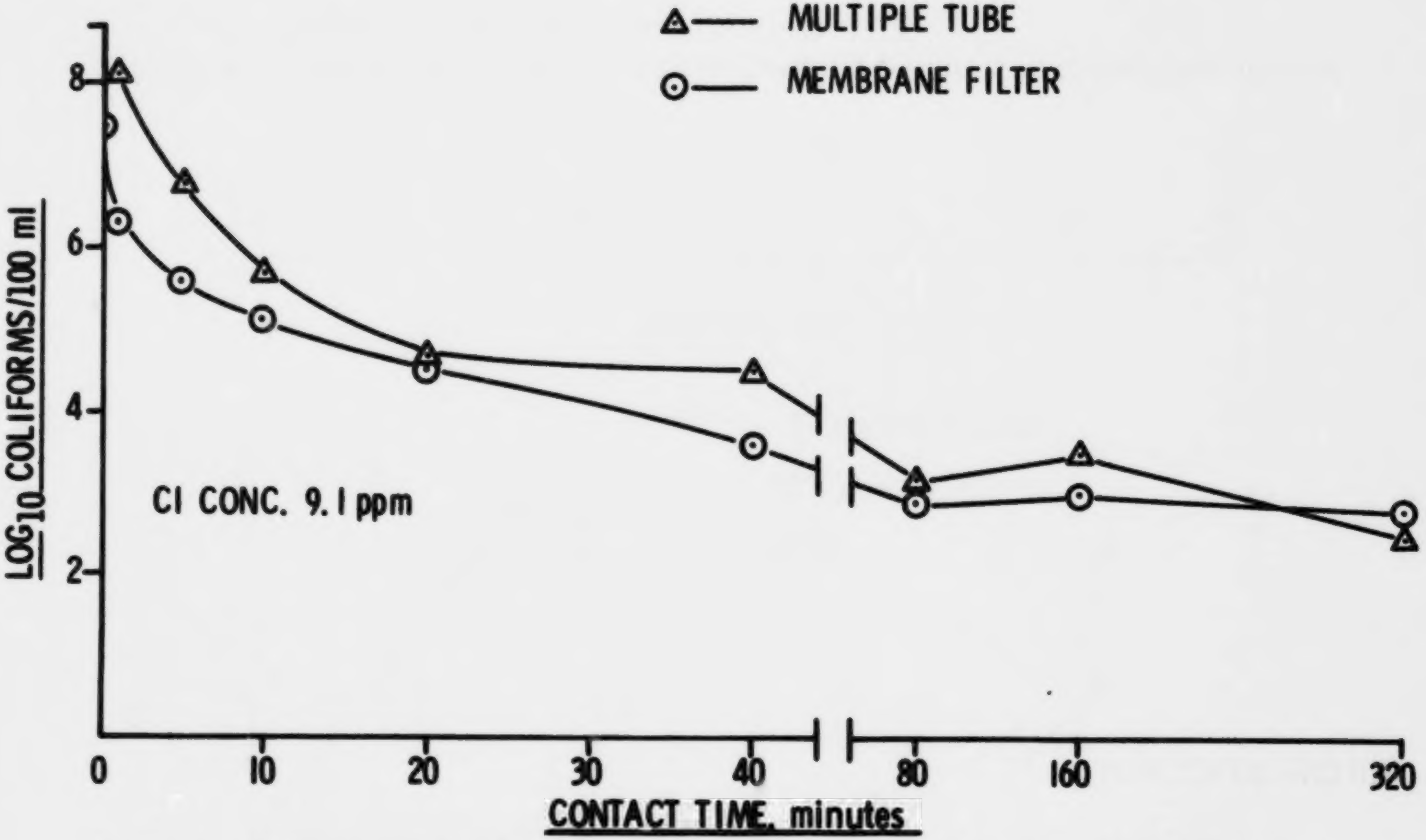


Figure 3. Comparison of methods for enumerating coliforms in chlorinated effluent. Mill trial of October 26, 1971.

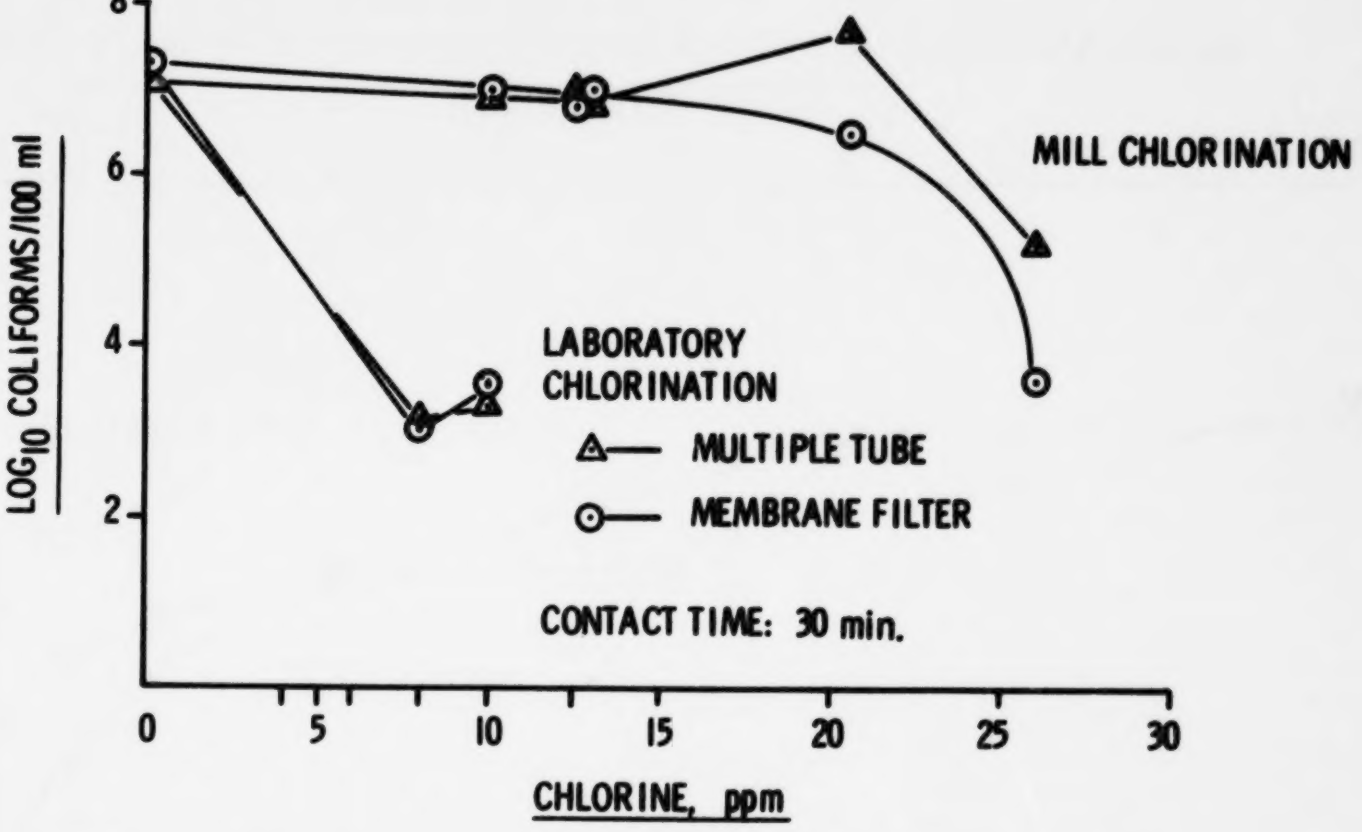


Figure 4. Comparison of methods for enumerating coliforms in chlorinated effluent. Laboratory and mill trials of March 16, 1972.

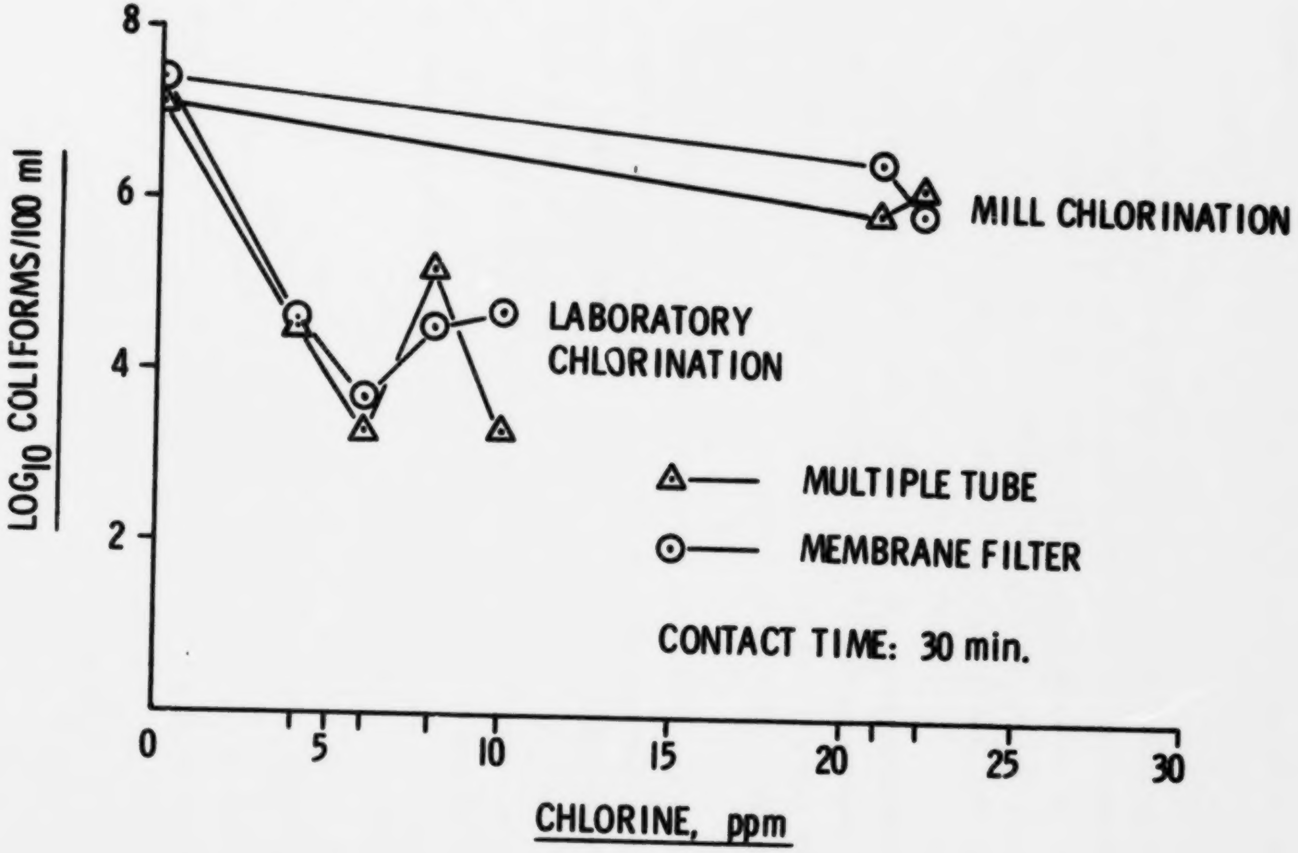


Figure 5. Comparison of methods for enumerating coliforms in chlorinated effluent. Laboratory and mill trials of March 17, 1972.

The MF method is better suited for the daily analysis of a large number of samples.

The MF method provides a definite number for bacterial concentrations so is appropriate for studying the effect of variables on bacterial populations. In contrast, the MT procedure indicates a range of concentrations. At the 95 percent confidence limits, the difference between upper and lower values may exceed one order of magnitude.[3]

In these preliminary tests the two methods gave comparable results. Conclusions concerning the order of magnitude of coliforms in various wastes or the effects of chlorination on coliforms would have been similar with data from either method.

The possibility was considered that coliforms exposed to chlorine or other adverse conditions might have a better chance for survival in lactose fermentation broth than they would on a membrane filter saturated with m-Endo Broth-mf. The latter medium which is used in the MF test contains surface active agents, ethanol and other compounds which might be inhibitory to coliforms in a weakened condition. For this reason, occasional analyses were made using the MT Presumptive test as well as the MF procedure.

REPRODUCIBILITY OF RESULTS

Reproducibility of the MF method was found to be good. Differences between duplicates averaged 17 percent for 30 samples of various types of wastes (Table 3). The greatest difference for a single sample was 122 percent or 0.62 $\log_{10}$ unit (Figure 6).

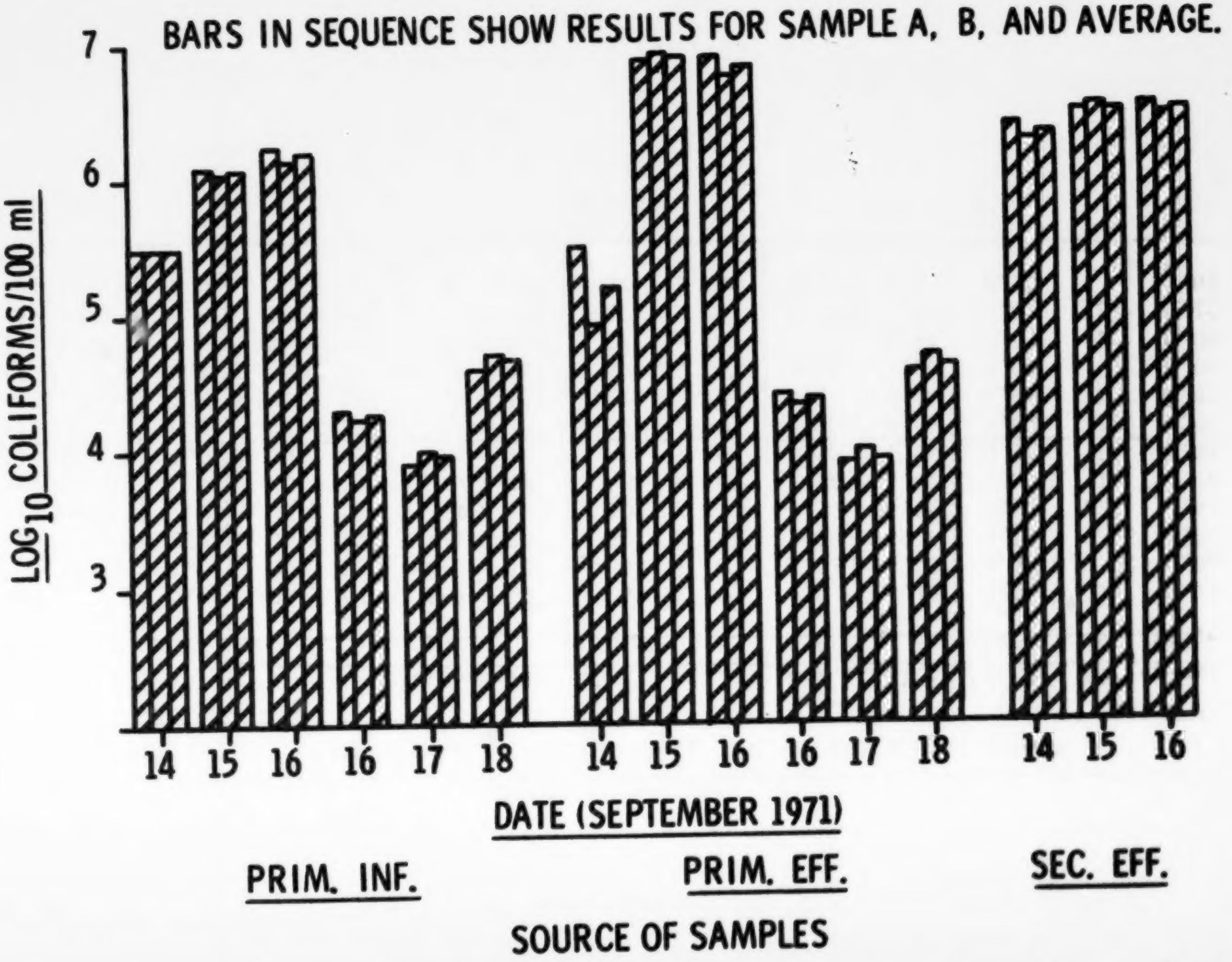


Figure 6. Reproducibility of coliform counts using the membrane filter method.

Table 3. REPRODUCIBILITY OF THE MEMBRANE FILTER METHOD FOR ENUMERATING COLIFORMS

Date (1971)	Sample	pH	Coliforms/100 ml			Log_{10} colif/100 ml			Difference	
			A	B	Ave.	A	B	Ave.	%	Log_{10}
9/14	1 Prim infl	9.0	102×10^4	130×10^4	116×10^4	6.01	6.12	6.07	24	0.11
	2 Prim infl, neut	7.0	30×10^4	30×10^4	30×10^4	5.48	5.48	5.48	0	0.00
	3 Prim eff	8.8	38×10^4	38×10^4	38×10^4	5.58	5.58	5.58	0	0.00
	4 Prim eff, neut	7.0	33×10^4	8×10^4	20.5×10^4	5.52	4.90	5.31	122	0.62
	5 Secondary infl	8.7	40×10^4	46×10^4	43×10^4	5.60	5.66	5.63	14	0.06
	6 Secondary eff	6.8	24×10^5	20×10^5	22×10^5	6.38	6.30	6.34	18	0.08
9/15	1 Prim infl	8.9	127×10^4	114×10^4	120×10^4	6.10	6.06	6.08	11	0.04
	2 Prim infl, neut	7.1	131×10^4	110×10^4	121×10^4	6.12	6.04	6.08	17	0.08
	3 Prim eff	8.8	40×10^4	40×10^4	40×10^4	5.60	5.60	5.60	0	0.00
	4 Prim eff, neut	7.0	74×10^5	82×10^5	78×10^5	6.87	6.91	6.89	10	0.04
	5 Secondary infl	8.6	24×10^4	30×10^4	27×10^4	5.38	5.48	5.43	22	0.10
	6 Secondary eff	6.8	32×10^5	34×10^5	33×10^5	6.51	6.53	6.52	6	0.02

Table 3 (continued). REPRODUCIBILITY OF THE MEMBRANE FILTER METHOD FOR ENUMERATING COLIFORMS

Date (1971)	Sample	pH	Coliforms/100 ml			Log$_{10}$ Colif/100 ml			Difference	
			A	B	Ave.	A	B	Ave.	%	Log$_{10}$
9/16	1 Prim infl	8.6	64 X 10^4	57 X 10^4	60.5 X 10^4	5.81	5.76	5.78	12	0.05
	2 Prim infl, neut	7.1	18 X 10^5	15 X 10^5	16.5 X 10^5	6.25	6.18	6.22	18	0.07
	3 Prim eff	8.6	76 X 10^4	82 X 10^4	79 X 10^4	5.88	5.91	5.90	8	0.03
	4 Prim eff, neut	7.0	84 X 10^5	69 X 10^5	76.5 X 10^5	6.92	6.84	6.88	20	0.08
	5 Secondary infl	8.4	26 X 10^5	35 X 10^5	30.5 X 10^5	6.42	6.54	6.49	30	0.12
	6 Secondary eff	7.0	34 X 10^5	31 X 10^5	32.5 X 10^5	6.53	6.49	6.51	9	0.04
9/16	7 Prim infl	3.8	40 X 10^2	38 X 10^2	39 X 10^2	3.60	3.58	3.59	5	0.02
	8 Prim infl, neut	7.0	22 X 10^3	19 X 10^3	20.5 X 10^3	4.34	4.28	4.31	15	0.06
	9 Prim eff	4.0	71 X 10^2	63 X 10^2	67 X 10^2	3.85	3.80	3.83	6	0.05
	10 Prim eff, neut	7.0	35 X 10^3	31 X 10^3	33 X 10^3	4.54	4.49	4.52	6	0.05
9/17	7 Prim infl	3.8	$<$100	100	$<$100	$<$2	2	$<$2	--	--[a]
	8 Prim infl, neut	7.2	84 X 10^2	98 X 10^2	91 X 10^2	3.92	3.99	3.96	15	0.07
	9 Prim eff	4.1	$<$100	100	$<$100	$<$2	2	$<$2	--	--
	10 Prim eff, neut	7.1	80 X 10^2	85 X 10^2	82.5 X 10^2	3.90	3.93	3.92	6	0.03
9/18	7 Prim infl	3.8	$<$100	$<$100	$<$100	$<$2	$<$2	$<$2	--	--
	8 Prim infl, neut	7.2	41 X 10^3	50 X 10^3	45.5 X 10^3	4.61	4.70	4.66	20	0.09
	9 Prim eff	4.1	$<$100	$<$100	$<$100	$<$2	$<$2	$<$2	--	--
	10 Prim eff, neut	7.1	20 X 10^3	17 X 10^3	18.5 X 10^3	4.30	4.23	4.27	16	0.07
Mean	--	--	--	--	--	--	--	--	17	0.08

[a] -- Unable to calculate.

EXPERIMENTAL POUR PLATE PROCEDURE

A pour plate procedure using WL Nutrient Medium (WLN) (Difco) was evaluated for enumerating coliforms. This medium, with a yeast inhibitor added, is formulated to detect bacterial contaminants in various fermentation processes.[4] It contains brom cresol green as an indicator of acid production. Since coliforms are acid producers the possibility was investigated that they could be distinguished and enumerated according to this ability.

It was found that acid was produced by bacteria from secondary effluent but its diffusion into the agar made it impossible to identify acid producing colonies. However, results based on total colony counts were encouraging. The mean ratio of total counts on WLN medium to coliforms as determined by the MF method, was 1.5:1 for 9 samples (Table 4). Extreme ratios ranged from 1.0:1 to 2.3:1. Of 41 colonies transferred from WLN plates to lactose broth fermentation tubes, 68 percent produced gas. This is the positive presumptive test for coliform bacteria. The mean total plate count made on WLN was only 2.6 percent of the mean total plate count obtained using Tryptone Glucose Extract Agar, TGE (Difco). The latter is a standard plate count medium used in the dairy industry.[4]

The results showed that the WLN plating medium, applied to Lebanon mill waste, was highly selective in enumerating only small percentages of total bacterial populations. Most bacteria recovered were coliforms but significant numbers of other types also grew on the plates. When considered in terms of orders of magnitude or $\log_{10}$ of populations (Figure 7), the correlation between MF counts of coliforms and WLN total counts appears to be good.

The selective action of WL Nutrient medium was probably due to its high sugar concentration of 50 g/l and relatively low pH of 5.5.

Table 4. EVALUATION OF A PLATE COUNT PROCEDURE USING WL NUTRIENT MEDIUM FOR ENUMERATING COLIFORMS

Sample description	Date (1971)	Bacteria/100 ml			WL nut. count: colif count	% of TGE total count		Lactose ferm by colonies from WL nut. med	
		Total count		Colif MF		WL nut.	Colif MF	# Tested	% Pos
		TGE	WL nut.						
Inf to primary	12/30	21×10^6	39×10^4	33×10^4	1.2	1.9	1.6	3	33
Inf to secondary	12/30	32×10^6	16×10^5	83×10^4	1.9	5.0	2.6	8	62
Sec effluent	12/8	11×10^9	46×10^5	40×10^5	1.2	0.04	0.04	5	100
Sec effluent	12/16	83×10^8	12×10^6	52×10^5	2.3	0.14	0.06	--[a]	--
Sec effluent	12/23	35×10^7	10×10^6	10×10^6	1.0	2.9	2.9	5	60
Sec effluent	12/27	89×10^6	74×10^5	54×10^5	1.4	8.3	6.1	--	--
Sec effluent	12/30	29×10^8	28×10^5	16×10^5	1.8	1.0	0.06	10	70
Chlorinated (2.7)	12/23	31×10^7	80×10^5	51×10^5	1.6	2.6	1.6	5	60
secondary (4.5)	12/23	39×10^7	72×10^5	58×10^5	1.2	1.8	1.5	5	80
effluent (10.6)	12/23	20×10^6	10^4	$< 10^4$	--	--	--	--	--
(Cl, ppm) (15.0)	12/23	10^2	10^2	$< 10^2$	--	--	--	--	--
(10.0)	12/27	50×10^3	2×10^2	$< 10^2$	--	--	--	--	--
Mean	--	--	--	--	1.5	2.6	1.8	41 (Total)	68

a -- Not done.

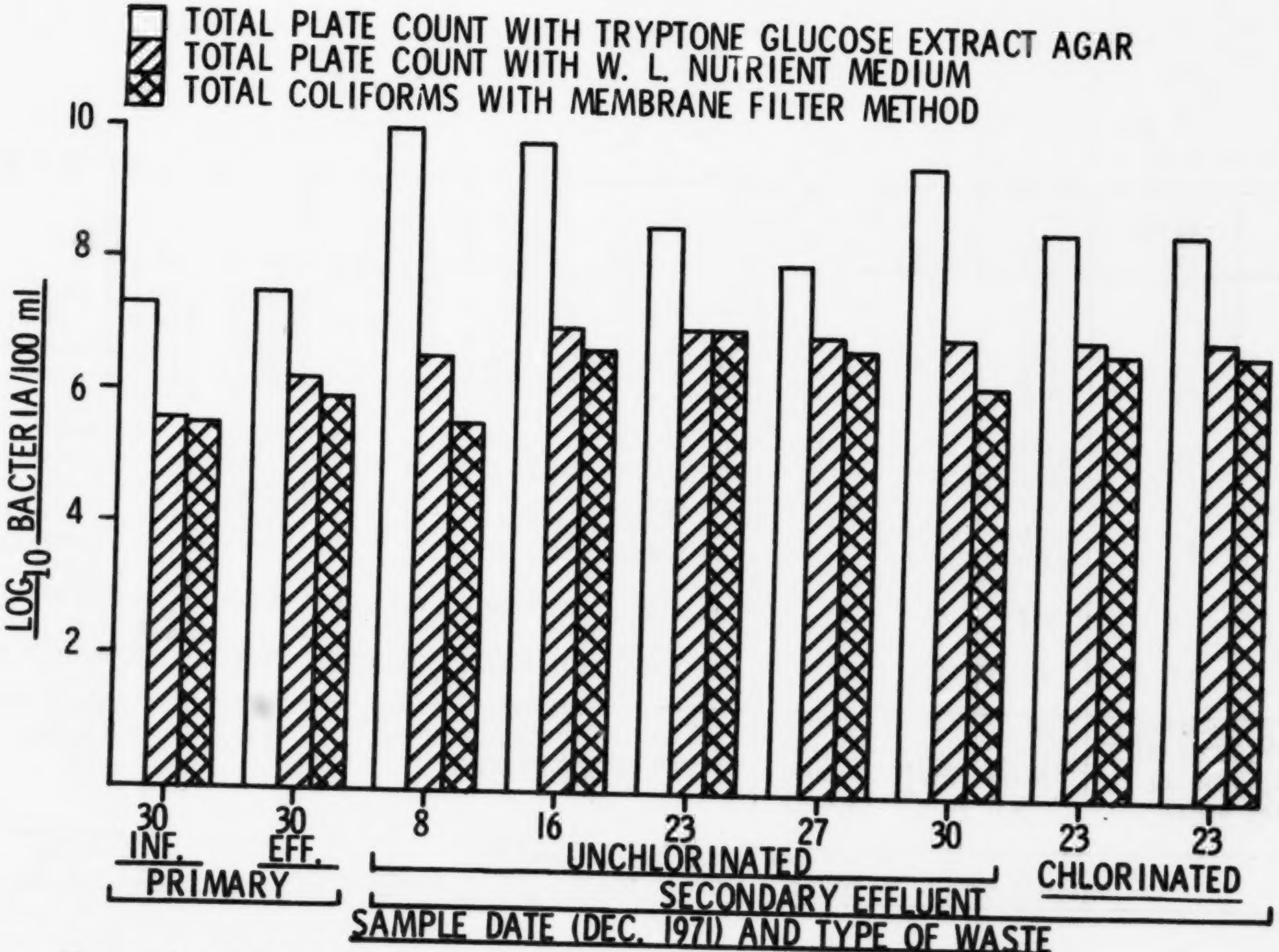


Figure 7. Evaluation of W. L. Nutrient Medium for enumerating coliforms and other bacteria in mill waste.

The usual environment in the Lebanon secondary ponds includes a pH of approximately 7 and a sugar concentration of less than 100 mg/l. Bacteria adapted to these conditions would find growth conditions hostile on WLN. These considerations suggest the possibility that coliforms are not indigenous to the secondary ponds.

A plate count method for enumerating coliforms would be much more rapid than the standard procedures. This saving in time becomes important as the number of required analyses increases. It is possible that the WL Nutrient Medium could be made more specific for coliforms by substituting lactose for glucose and by incubating plates at 35° C. rather than at 20-25° C. as was done in this study.

SECTION VI

BACTERIA IN AERATED STABILIZATION BASINS

CONCENTRATIONS

Coliform concentrations in secondary effluent ranged from 300 thousand to 150 million per 100 ml during parallel operations of the ponds (Table 5).

Table 5. CHARACTERISTICS OF SECONDARY COMPOSITE EFFLUENT DURING PARALLEL OPERATION. SUMMARY OF DATA.

Measurement	No. of analyses	Mean	S.D.[a]	Var, %	Range
pH	104	7.1	0.5	--[b]	5.4-7.4
Temp, °C.	93	23.5	4.9	21	12.0-32.4
SO_3, ppm	22	3.6	0.6	17	2.8-4.9
BOD, ppm	107	106	25	24	72-192
Total bact/100 ml X 10^7	82	284	256	90	9-1000
Coliforms/100 ml X 10^5	107	251	291	116	3-1500
Coliforms, % of total bacteria	82	1.9	2.2	116	0.01-16.5

[a] S.D. - Standard Deviation.

b -- Not calculated.

The mean of 107 analyses made over a 15 month period was 25 million per 100 ml with a standard deviation of 29 million per 100 ml. This variation in counts was studied in more detail by comparing results obtained for samples collected during a single day with those obtained for samples collected on different days and during different months. The variation among hourly samples was 19 percent as compared with 86 percent and 93 percent for daily and monthly samples, respectively (Table 6). This indicates that the coliform population was responding to changes in conditions and that the variations found were not due to sampling or analytical problems.

Although coliform concentrations in secondary effluent seldom were less than one million per 100 ml, they represented only a small segment of the total bacterial population. On the basis of mean viable counts for a 15 month period (Table 5), coliform concentrations were less than two percent of total bacterial concentrations. Individual values are given in Table I in the Appendix.

During the 15 month interval the total viable bacterial population averaged 2.8 billion cells per 100 ml (Table 5) and varied less than did the coliforms. Microscopic counts made on preserved samples indicated higher bacterial concentrations, ranging from 6.2 to 42 billion per 100 ml (Table 7). The difference between viable and microscopic counts could be due to a combination of the following:

The microscopic methods did not distinguish between live and dead cells. It is possible that a large percentage of the cells counted were dead.

Plating conditions were not appropriate for a large segment of the bacterial population. For example, the medium used was probably too rich in nutrients and the incubation time too short to support growth of prosthecate bacteria which were present in significant numbers (Table 7).

Table 6. VARIATIONS IN BACTERIA IN SECONDARY EFFLUENT DURING PARALLEL POND OPERATION

Month	Day(s)	Total bacteria				Coliforms			
		# of values	X 10^7/100 ml		Var., %	# of values	X 10^5/100 ml		Var., %
			Mean	S.D.			Mean	S.D.	
Dec. (1971)	31	--[a]	--	--	--	2	21.5	4.9	23
Hourly values	31	--	--	--	--	2	--	--	23
Daily values	13-31	--	--	--	--	7	36.8	33	90
March (1972)	13	2	67	13	19	2	115	35	30
	14	4	66	28	73	6	220	58	26
	15	3	173	55	32	3	123	21	17
	16	2	145	7.1	5	2	195	7.1	4
	24	3	71	22	31	3	417	68	16
Hourly values	13-24	14	--	--	38	16	--	--	20
Daily values	13-24	8	110	46	42	8	215	127	59
May (1972)	18	3	550	115	21	3	840	147	18
Hourly values	18	3	--	--	21	3	--	--	18
Daily values	18,25	1	550	--	--	2	695	205	29
June (1972)	13	2	410	71	17	2	100	28	28
Hourly values	13	2	--	--	17	2	--	--	28
Daily values	8-30	8	504	247	49	11	217	126	58
July (1972)	6	2	480	28	6	2	51	1.4	3
	7	--	--	--	--	2	21	7.1	34
	8	--	--	--	--	3	23	1.2	5
	11	--	--	--	--	2	111	30	27
Hourly values	6-11	2	--	--	6	9	--	--	16
Daily values	5-31	3	427	61	14	12	175	240	137
Dec. 13, 1971 to July 31, 1972									
Hourly values		21	--	--	31	32	--	--	19
Daily values		19	--	--	41	40	--	--	86
Monthly values		4	398	198	50	5	268	250	93

[a] -- Not done or calculated.

Table 7. DIFFERENTIAL MICROSCOPIC COUNTS OF SECONDARY INFLUENT AND EFFLUENT
(Courtesy of Drs. E. J. Ordal and J. T. Staley, Univ. of Wash.)

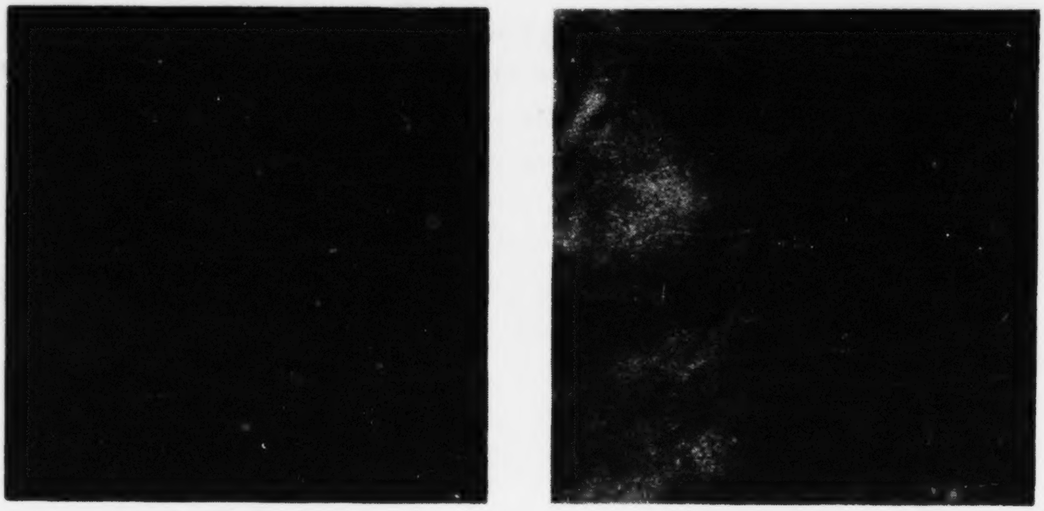
Analysis	November 30, 1971			March 9, 1972			November 2, 1972		
	Inf.	Pond 1	Pond 2	Inf.	Pond 1	Pond 2	Inf.	Pond 1	Pond 2
Total microscopic count, cells per 100 ml X 10^7	99	620	675	--[a]	590	800	0.03	4200	3500
Differential count, percent of total count									
Rods	98	47	65	87	9.5	6.6	92	44	42
Prosthecomicrobium	<1	9.3	1.0	<1	<1	2.9	<1	<1	2.0
Ancalomicrobium	1.0	21	14	<1	32	40	<1	4.0	5.0
Hyphomicrobium	<1	<1	7.9	<1	18	15	<1	<1	<1
Caulobacter I	<1	1.8	5.9	<1	12	11	<1	1.0	6.0
Caulobacter II	<1	<1	<1	<1	6.0	5.1	<1	<1	<1
Spirillum, thin	1.0	4.6	4.3	11	17	2.9	4	3.0	<1
Spirillum, fat	<1	1.4	0.6	<1	3.1	15	<1	<1	5.0
Actinomycetes	<1	15	1.4	2.0	<1	<1	<1	2.0	1.0
Vibrios, large	<1	<1	<1	<1	<1	<1	<1	10	15
Vibrios, small	<1	<1	<1	<1	<1	<1	4	4.0	8.0
Cocci	<1	<1	<1	<1	<1	<1	1	12	5.0
Bent rods	<1	<1	<1	<1	<1	<1	<1	9.0	2.0
Spirochaetes	<1	<1	<1	<1	<1	<1	<1	8.0	7.0
Unclassified	<1	<1	<1	<1	2.4	1.5	<1	2.0	2.0

[a] Not done.

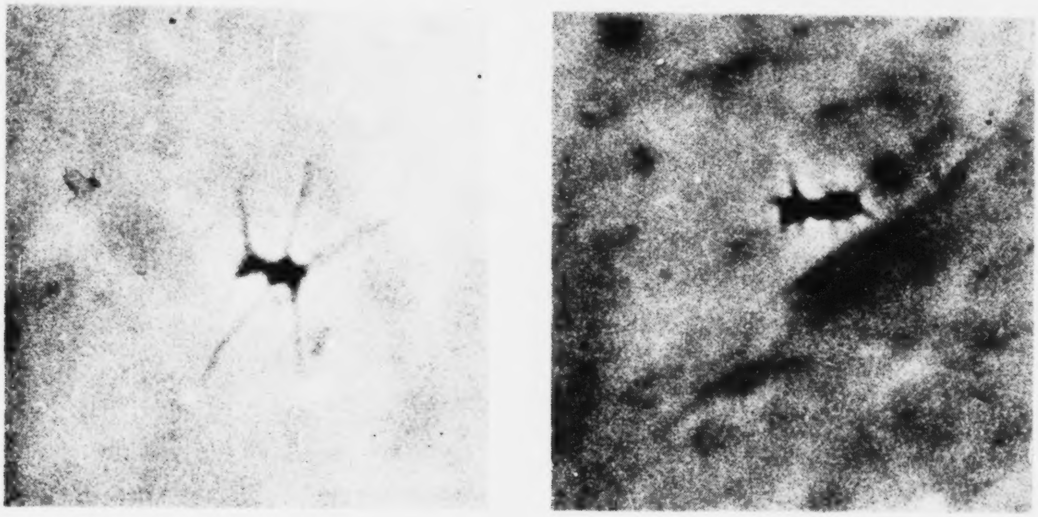
Microscopic counts of March 9 substantiate the conclusion, based on viable counts, that coliforms represent only a small fraction of the total bacterial population in secondary treatment ponds. On this date less than 10 percent of the total bacteria were rod-shaped and it is probable that only a small portion of these were coliforms. No conclusions can be drawn on microscopic counts of other days. Rod-shaped bacteria represented a major segment of total bacteria but coliforms could not be distinguished microscopically.

TYPES

Routine microscopic observations showed that the secondary ponds were inhabitated by significant numbers of bacteria with unusual shapes. They were called to the attention of E. J. Ordal and J. T. Staley (University of Washington) who recognized them as prosthecate bacteria. The term prostheca refers to rigid cellular appendages. Staley[5] discovered two types of prothecate bacteria in fresh water and proposed the new genera classification Ancalomicrobium and Prosthecomicrobium. He has observed these bacteria as well as members of the genera Caulobacter and Hyphomicrobium in Lebanon secondary effluent (Figure 8, Table 7). All strains of prosthecate bacteria studied by Staley[5] required vitamins and grew rather slowly in media with low concentrations of carbohydrates. Other studies suggest that the appendages of prosthecate bacteria reduce the rate of settling[6] or function to increase surface membrane area to allow the bacteria to grow in environments which are low in nutrients.[7] Prosthecate bacteria obviously multiplied in the secondary ponds (Table 7) but the role of this interesting group of organisms in secondary treatment was not determined. Their presence may be an indication that concentrations of soluble carbohydrates have been reduced to relatively low levels.



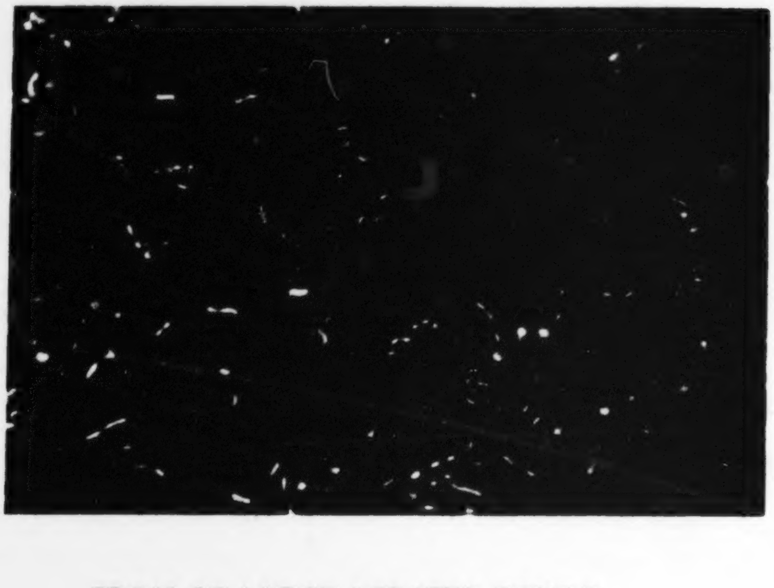
HYPHOMICROBIUM CAULOBACTER



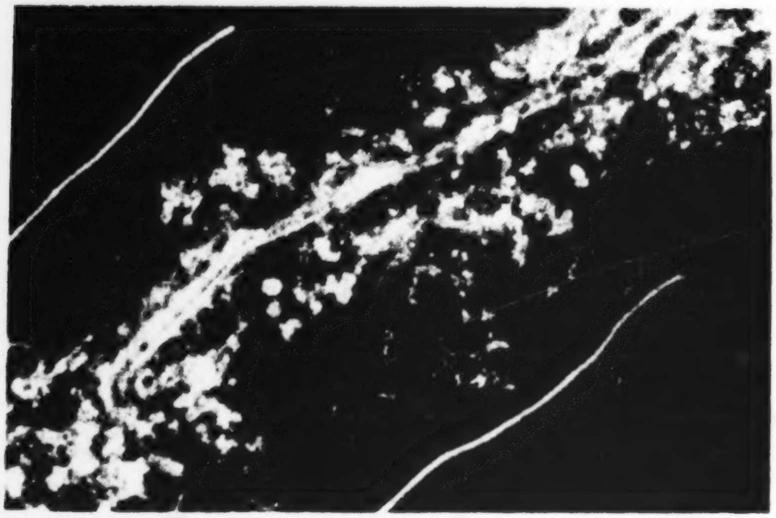
PROSTHECOMICROBIUM ANCALOMICROBIUM

Figure 8. Prosthecate bacteria in Lebanon secondary effluent. "Courtesy of Dr. J. T. Staley, Univ. of Washington." Approximate magnification 4000x.

Several other morphological types of bacteria were observed in secondary effluent (Table 7, Figure 9). Routine microscopic observations showed that concentrations of motile bacteria, especially spirilla, were frequently inversely related to concentrations of protozoa.



FROM CZ LARGE AERATED PONDS



FROM EPA UNIT

Figure 9. Bacteria in secondary effluent. Approximate magnification 1600x.

SECTION VII

EFFECT OF VARIABLES ON CONCENTRATIONS OF BACTERIA IN SECONDARY EFFLUENT

INOCULATION

Aerated Basins

Effluent from the primary settling pond is the immediate source of bacteria for the aerated secondary basins. Primary effluent is equivalent to secondary influent except that the latter has been supplemented with H_3PO_4 and neutralized with ammonia when necessary. The mean coliform concentration of 86 secondary influent samples analyzed over a 15 month period was 77 million per 100 ml (Table 8).

Table 8. CHARACTERISTICS OF SECONDARY INFLUENT. SUMMARY OF DATA.

Measurement	No. of analyses	Mean	S.D.	Var, %	Range
pH[a]	58	6.9	2.1	--[b]	3.2-10
Temp, °C.	78	34.2	4.3	13	25.5-46
SO_3, ppm	30	142	72	51	71-322
BOD, ppm	86	413	57	14	240-560
Total bact/100 ml X 10^7	68	44	152	345	0.2-980
Coliforms/100 ml X 10^5	86	773	1630	211	0.02-11,000
Coliforms, % of total bacteria	68	19	22	116	0.001-100

[a] Before neutralization.

[b] Not calculated.

This was three times greater than the mean found for secondary effluent samples during a similar period (Table 5). Complete data for influent samples are given in Table II in the Appendix.

Inoculation by primary effluent must be considered as a major influence on coliform levels in secondary ponds.

Variations in bacterial concentrations, especially coliforms, in secondary influent (Figure 10) were much greater than found for secondary effluent (Figure 11). Possible reasons for this will be discussed in the sections dealing with the effect of pH on coliform concentrations. As with secondary effluent, coliform variation was greater among daily samples than among hourly samples (Table 9). Over longer periods of time the factors influencing counts tended to equalize. Variations over monthly intervals approached those found for hourly samples.

The following comparisons suggest the interesting possibility that coliforms are proliferating in the primary pond or within the mill and that their presence in secondary effluent is the result of continual inoculation:

The total bacterial population increases during secondary treatment whereas coliforms decrease (Table 10).

In secondary effluent coliforms represent less than 2 percent of the total bacteria (Table 5) compared to 19 percent for the daily mean of influent samples (Table 8). Individual values exceeding 40 percent were not unusual for influent and in two samples the entire population seemed to be coliforms.

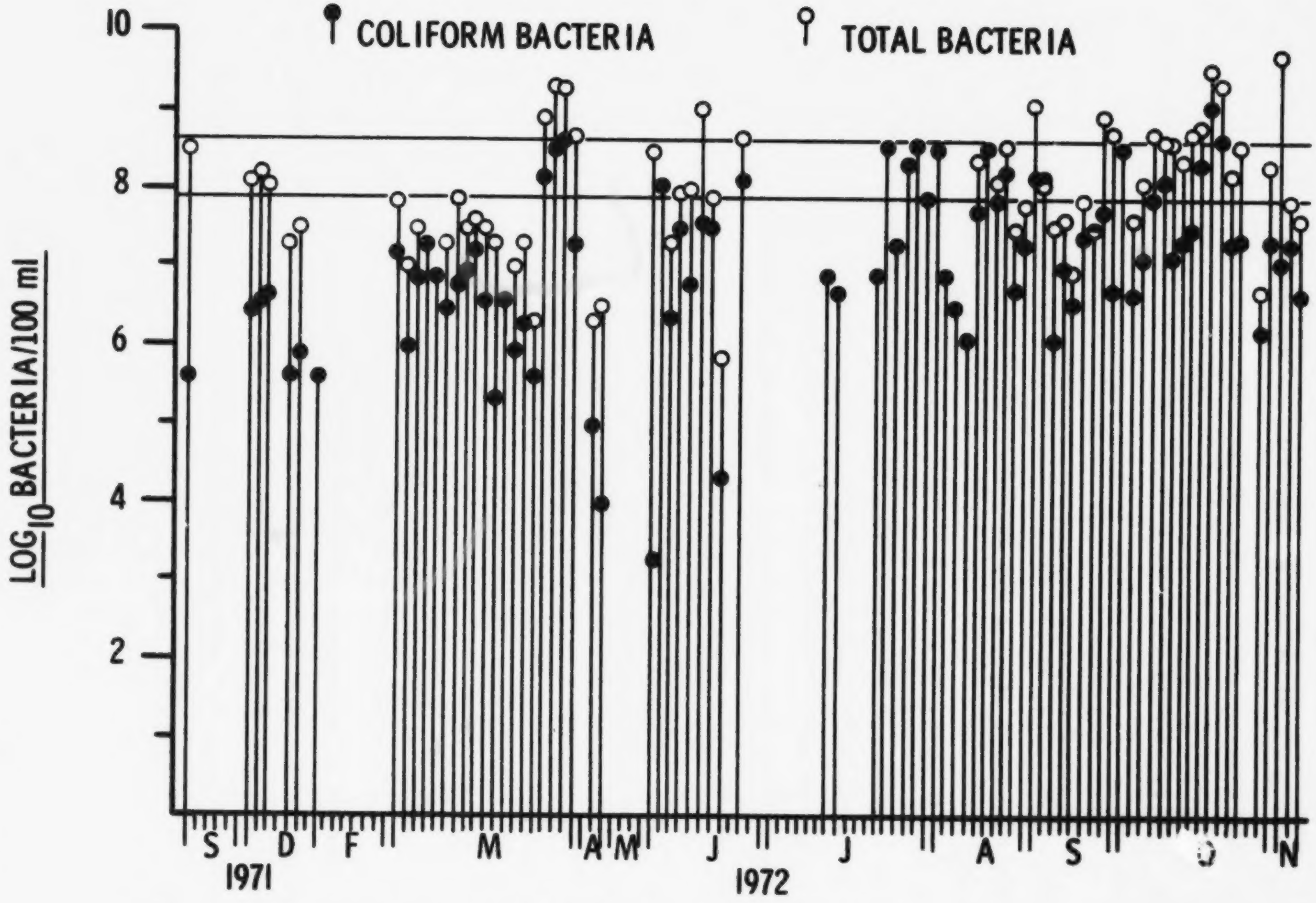


Figure 10. Concentrations of bacteria in secondary influent during parallel operation.

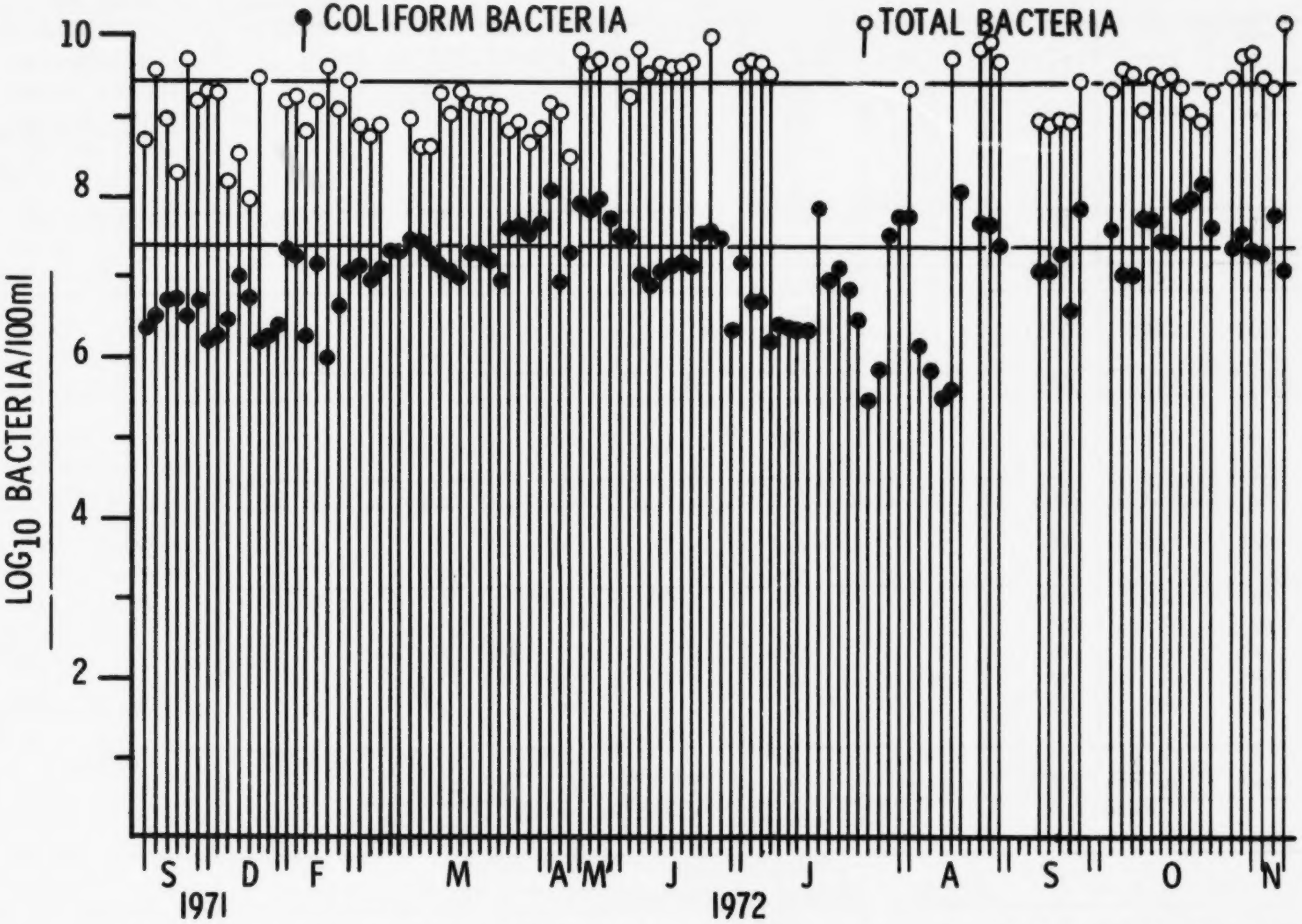


Figure 11. Concentrations of bacteria in secondary effluent during parallel operation.

Table 9. VARIATIONS IN BACTERIA IN SECONDARY INFLUENT DURING PARALLEL POND OPERATION

Month	Day(s)	Total bacteria # of values	Total bacteria X 10^7/100 ml Mean	Total bacteria X 10^7/100 ml S.D.	Total bacteria Var., %	Coliforms # of values	Coliforms X 10^5/100 ml Mean	Coliforms X 10^5/100 ml S.D.	Coliforms Var., %
March (1972)	13	2	4.0	3.2	80	2	85	106	125
	14	4	3.8	2.2	58	6	86	59	69
	15	3	3.0	1.0	33	3	65	84	130
	16	--[a]	--	--	--	2	24	21	88
	24	3	139	80	58	3	2490	2030	82
Hourly values	13-24	12	--	--	55	16	--	--	92
Daily values	13-24	8	29	52	179	8	518	922	178
June (1972)	13	2	9.5	0.71	7.5	2	175	163	93
Hourly values	13	2	--	--	7.5	2	--	--	93
Daily values	8-28	8	26	37	142	8	272	439	161
July (1972)	8	0	--	--	--	2	260	255	98
Hourly values	8	0	--	--	--	2	--	--	98
Daily values	8-31	0	--	--	--	7	1490	1560	105
Sept. (1972)	15	2	66	76	115	2	1450	71	4.9
Hourly values	15	2	--	--	115	2	--	--	4.9
Daily values	15-29	8	28	35	125	8	338	479	142
March 13 to Sept. 29, 1972									
Hourly values		16	--	--	57	22	--	--	85
Daily values		24	--	--	149	31	--	--	148
Monthly values		3	28	1.6	5.7	4	654	567	87

[a]-- Not done or calculated.

Table 10. EFFECT OF SECONDARY TREATMENT ON CONCENTRATIONS OF BACTERIA

Date	Total bacteria			Coliforms		
	Cells/100 ml X 10^7		Ratio	Cells/100 ml X 10^5		Ratio
	Influent	Effluent	Effluent:influent	Influent	Effluent	Effluent:influent
September, 1971	70	197	2.8	4	39	9.8
December, 1971	9	132	14.7	20	37	1.8
March, 1972	29	110	3.8	518	215	0.4
April, 1972	0.3	104	347.0	1	533	533
June, 1972	26	503	19.3	272	217	0.8
July, 1972	--[a]	--	--	1490	175	0.1
August, 1972	16	564	35.2	953	335	0.4
September, 1972	28	130	4.6	338	240	0.7
October, 1972	61	312	5.1	1580	483	0.3
November, 1972	140	720	5.1	873	317	0.4
Mean	42	308	7.3	605	259	0.4

[a] -- Not determined.

An increase in coliforms in effluent during the period from December through March (Figure 10) reflected a similar increase in influent samples (Figure 11).

These data are suggestive, however, other considerations prevent the drawing of definite conclusions:

Waste treatment is continuous and the grab samples analyzed represent only a very small fraction of the total waste.

In spite of wide fluctuations in coliforms in secondary influent (Figure 10), populations remain relatively stable in effluent (Figure 11) and do not always reflect changes in influent concentrations.

The finding that coliforms represent only a small percentage of the total number of bacteria in secondary ponds may be related to the concentration of nutrients in the ponds rather than to the number of coliforms going into the ponds.

Small Scale System

The opposing viewpoints regarding the significance of coliforms and the importance of inoculation are difficult to resolve using full scale equipment. Removal or control of coliforms in secondary influent and elimination of bottom deposits within the secondary ponds, as sources of coliforms, were considered to be problems beyond the scope of this study. As an alternative small scale treatment units (Figure 12) were constructed to evaluate, under controlled conditions, the relationships between coliform inoculation and the concentrations of coliforms in secondary treatment ponds. Main stages of the experimental unit (Figure 13) included:

Influent Settling - to prevent particles from getting into small bore tubing and the metering pump.

Influent Acidification - to reduce coliform concentrations.

Neutralization - to adjust influent back to its original pH.

Aeration and Retention - to simulate secondary pond operation.

This sequence of operations is similar to that occurring in the full scale operation when acidic by-products are being manufactured.

A control unit utilized only the first and last stages. Here, the final aerated stage received approximately the same inoculation with coliforms as did the large mill secondary ponds.

Components of the treatment systems and their retention times are given in Table 11. A more complete description of the units and their operation is provided in the Apparatus and Methods section. Complete analytical data for the small scale units are given in Table III in the Appendix.

Coliform concentrations were greatly reduced in the small scale aeration unit, No. 9, by reducing the number of coliforms going into it (Figure 14, Table 12). During the first 10 days the system had several upsets and coliform kill in influent was erratic. From October 16 on, operations were normal. This, plus the addition of mechanical mixing to the acidification stage, led to further coliform reductions in both influent and effluent. From October 24 on, coliform reduction due to reduced inocula exceeded 99.8 percent. All coliforms in influent were not killed by the acidification procedure even though the pH was consistently below 2 (Table III, Appendix).

The total bacterial population in secondary influent also was greatly reduced by the acidification procedure (Table 12). However, this had no adverse effect on the total population in the aeration unit. Except

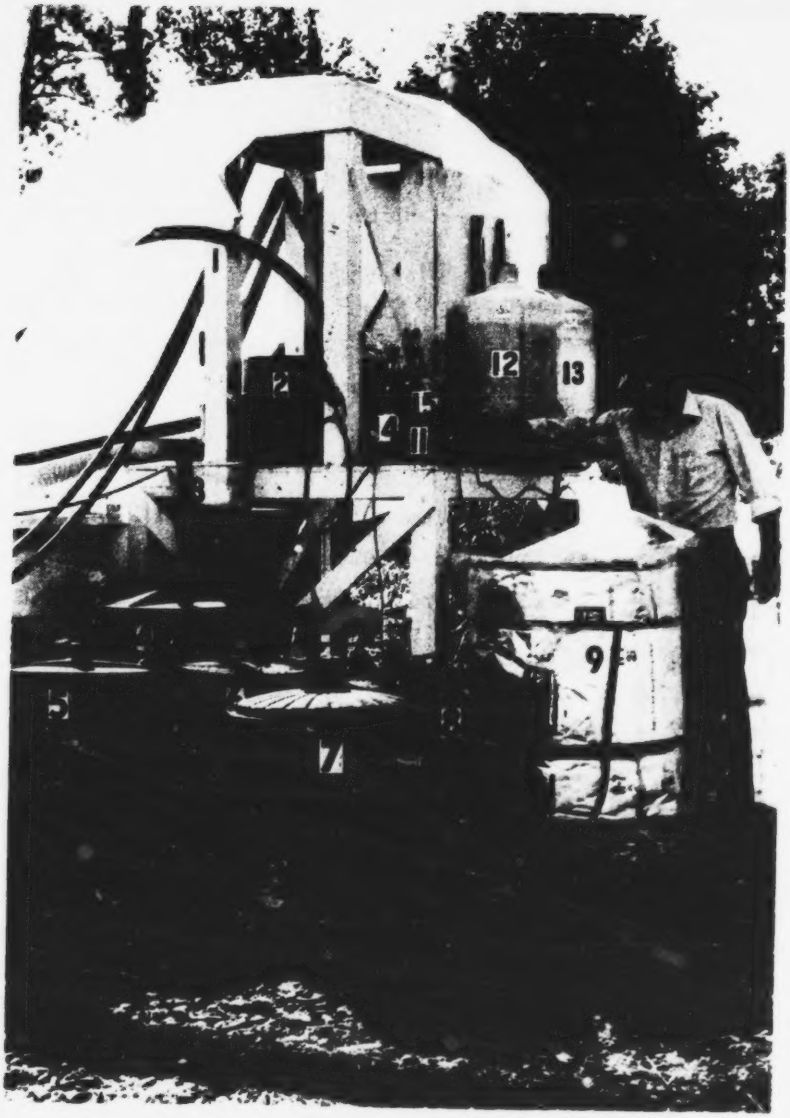

12
13
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Figure 12. Small scale waste treatment system.

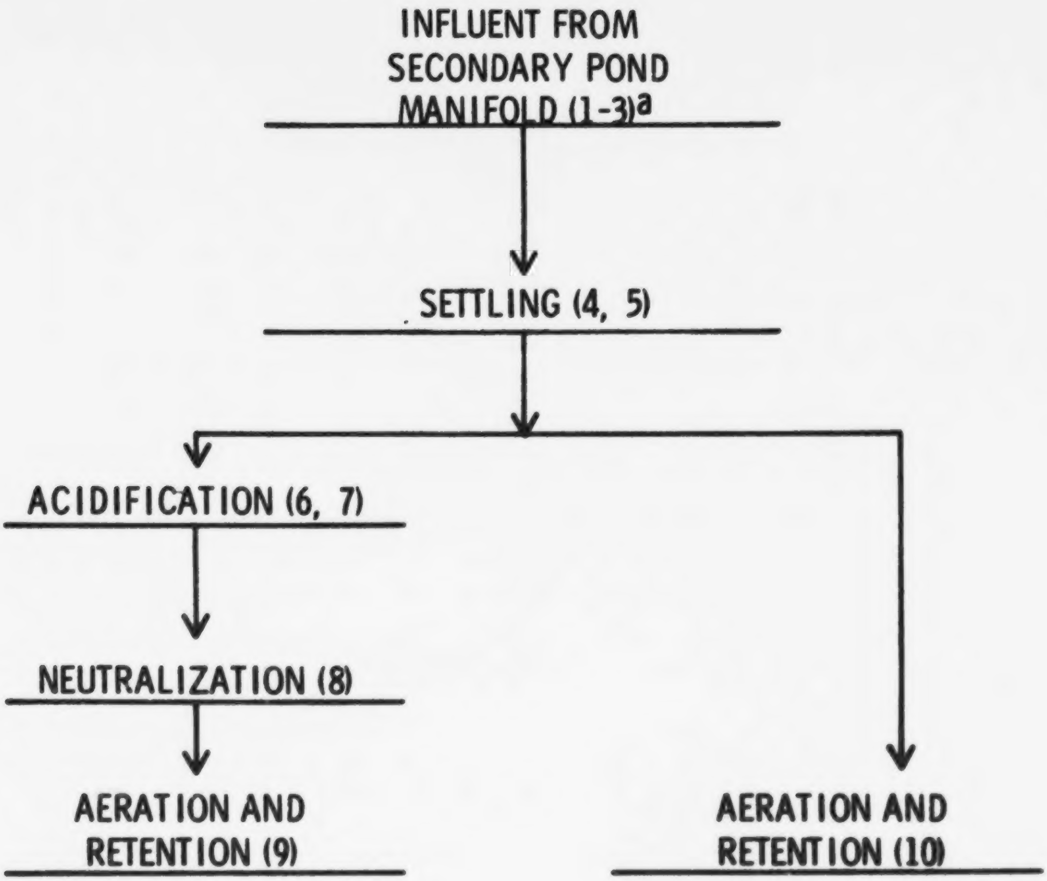
INFLUENT FROM SECONDARY POND MANIFOLD (1-3)[a]
SETTLING (4, 5)
ACIDIFICATION (6, 7)
NEUTRALIZATION (8)
AERATION AND RETENTION (9)
AERATION AND RETENTION (10)

Figure 13. Main stages of small scale treatment system.

[a] Numbers refer to units shown in Figure 12.

Table 11. COMPONENTS OF SMALL SCALE WASTE TREATMENT SYSTEM

Unit no.	Description	Capacity, liters	Flow, L/min minus excess		Retention time, hours
			In	Out	
1	Influent line	700	22	22	0.53
2	Constant level head box	40.8	22	1.5	0.031
3	Waste basket (flow director)	Nil	1.5	1.5	Nil
4	Settling basin 1	99.5	1.5	1.5	1.1
5	Settling basin 2	56.0	1.5	1.5	0.62
6	Acidification unit	53.2	1.5	1.5	0.54
7	Acidified influent retention unit	76.0	1.5	1.5	0.83
8	Neutralization unit	48.4	1.5	0.032	0.54
9	Experimental aeration unit	234 (inc. heater)	0.032	0.032	122 (5.1 Days)
10	Control aeration unit	242 (inc. heater)	0.032	0.032	126 (5.25 Days)

Table 11 (continued). COMPONENTS OF SMALL SCALE WASTE TREATMENT SYSTEM

Unit no.	Description	Capacity, liters	Flow, L/min minus excess		Retention time, hours
			In	Out	
11	Peristallic metering pump	--^{a}	--^{a}	--^{a}	--^{a}
12	Acid reservoir	50.0	--^{a}	0.028	29.8
13	Caustic reservoir	50.0	--^{a}	0.028	29.8
14	Reserve acid supply	3.8	--^{a}	0.028	0.23
15	Reserve caustic supply	3.8	--^{a}	0.028	0.23
16	Recirculation and aeration pump for 9	--^{b}	--^{b}	--^{b}	--^{b}
17	Heating unit for 9	--^{b}	--^{b}	--^{b}	--^{b}
18	Recirculation and aeration pump for 10	--^{b}	--^{b}	--^{b}	--^{b}
19	Heating unit for 10	--^{b}	--^{b}	--^{b}	--^{b}

[a] No significant capacity or continuous flow.

[b] Included in value for aeration unit.

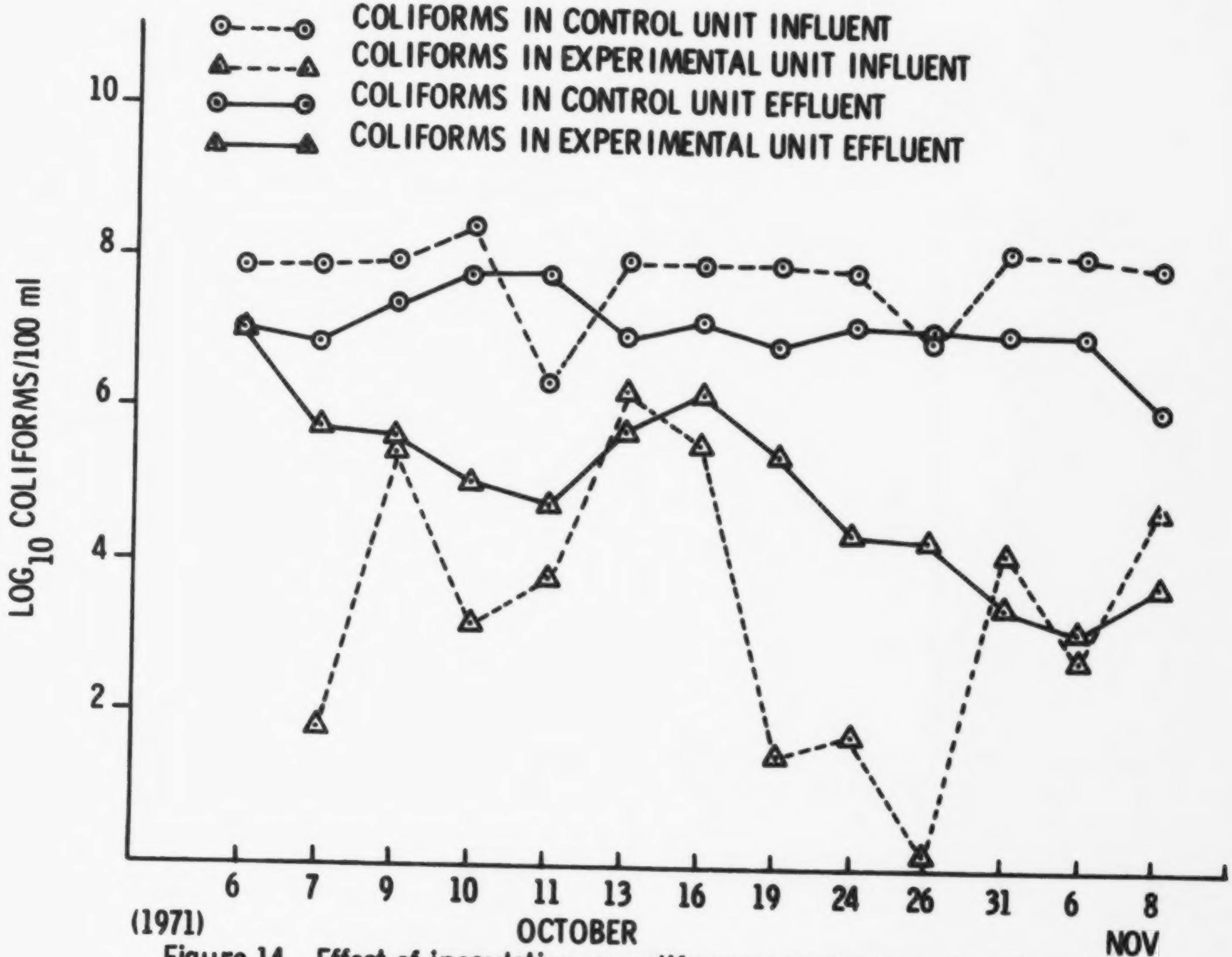

Figure 14. Effect of inoculation on coliform concentrations in effluents from small scale treatment units.

Table 12. EFFECT OF INOCULUM ON BACTERIAL CONCENTRATIONS IN SMALL SCALE SECONDARY TREATMENT UNITS

Date (1972)	Elap. time, days	Influent						Effluent					
		Total bacteria			Coliforms			Total bacteria			Coliforms		
		X 10^7/100 ml		Red., %[a]	X 10^5/100 ml		Red., %[a]	X 10^7/100 ml		Red., %[a]	X 10^5/100 ml		Red., %[a]
		Cont.	Exp.		Cont.	Exp.		Cont.	Exp.		Cont.	Exp.	
Oct. 6	Start	260	0.0004	>99.99	700	<0.0001	>99.99	490	360	--[b]	130	130	--
7	0.9	53	0.0005	>99.99	750	0.0007	>99.99	320	270	15.6	80	6.0	92.50
9	2.8	370	0.70	99.81	>1000	2.9	>99.99	40	28	30.0	230	5.0	97.83
10	4.0	150	0.0030	>99.99	2400	0.022	>99.99	220	200	9.1	680	1.2	99.82
11	4.8	170	0.0050	>99.99	26	0.060	99.77	180	280	+56	600	0.70	99.88
13	7.0	210	2.2	98.95	1000	20	98.00	200	500	+150	120	6.3	94.75
16	10.0	290	3.9	98.66	900	3.6	99.60	730	13	98	170	19	88.82
19	13.0	290	0.0004	>99.99	1200	0.0003	>99.99	590	880	+49	80	3.4	95.75
24	18.0	60	0.0010	>99.99	800	0.0006	>99.99	140	170	21	160	0.31	99.81
26	20.0	5.6	0.0020	99.96	100	<0.0001	>99.99	520	940	+81	140	0.24	99.83
31	25.0	110	0.049	99.96	1600	0.18	>99.99	1000	820	18	130	0.029	99.98
Nov. 6	31.0	66	0.0079	>99.99	1400	0.007	>99.99	870	620	29	120	0.014	99.99
8	33.0	590	0.69	88.31	1000	0.69	99.93	150	110	27	13	0.060	99.54
Mean (Exc. Oct. 6)	--	197	0.63	99.68	>1010	<2.29	>99.77	413	403	2.4	210	3.52	98.32
S.D.	--	167	1.2	--	--	--	--	320	338	--	208	5.45	3.82

[a] Percent reduction due to influent treatment.

[b] -- Not measured or calculated.

for October 16, total bacteria concentrations were similar for the two small scale aeration units and the mill secondary ponds (Figure 15).

Results from this experiment showed that coliforms, at least in high concentrations, were not normal inhabitants of the small aeration units. This suggests the possibility that coliforms might be reduced to acceptable concentrations in the large aerated lagoons if a practical way could be found to reduce their numbers in the influent.

pH

Direct Effects

The pH of secondary ponds varied little during the project. The mean of 104 samples was 7.1 ± 0.5 S.D. (Table 5). Only during three brief periods in June and July, 1972 did the pH fall below 6.0. Between June 15 and 20 the pH dropped to a low of 5.6 but coliform concentrations remained in the range of normal variation (Figure 11). Similar situations and results were found on July 5, 6, and 11. pH values in the range of 5.4 to 5.7 had no immediate adverse effect on coliform populations. However, it may be significant that coliform populations reached their lowest level of the entire project about 10 days after the last interval of low pH. Microscopic observations made during periods of low pH showed a qualitative shift in microorganisms away from spirilla, vibrios and prosthecate bacteria toward cocci, non-motile rods, yeast and protozoa. This suggests that low pH led to a slow change in the balance of microorganisms, temporarily favoring predators of coliforms. The cyclic nature of coliform populations (Figure 11) suggests a predator-prey relationships, however, other factors such as varying concentrations of coliforms in secondary influent may be responsible for this.

The highest pH values of secondary effluent, 7.3 to 7.4, had no adverse effect on coliform concentrations (Table I, Appendix).

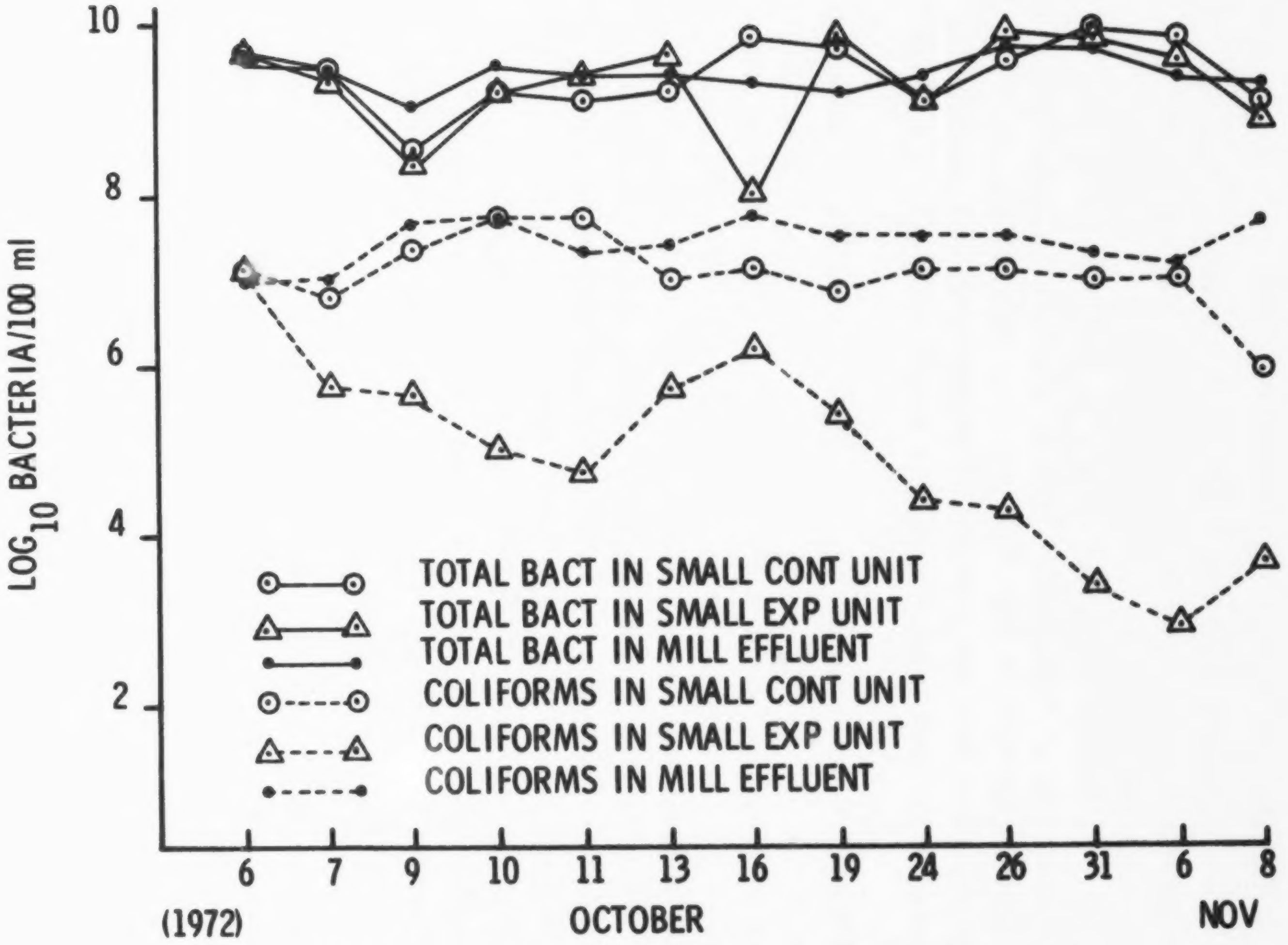

Figure 15. Comparison of concentrations of bacteria in mill and small scale systems.

Indirect Effects

There is an indirect pH effect which merits consideration. Experiments with small scale apparatus (Table III, Appendix) showed that acidification greatly reduced coliforms in secondary influent. When the acidified influent was neutralized and fed to an aeration unit, coliform regrowth was negligible. In fact, there was rapid die off of those initially present (Figure 14). These processes of influent acidification and retention, followed by neutralization and transfer to aeration units have their counterparts in full scale mill operations.

Approximately 40 percent of the total mill waste is utilized to establish the "water leg"* for an evaporator used in the manufacture of commercial lignosulfonates. When acidic grades are being produced, SO_2 volatilizes from spent sulfite liquor within the evaporator and dissolves in the mill waste "water leg". This stream in turn combines with other wastes which are fed to the primary settling pond (Figure 16). This constitutes the influent acidification stage. The SO_2 lowers the pH of the "water leg" to pH 2-3 (Table 13). Combined waste, which is equivalent to secondary influent before neutralization, may have pHs in the range of 3-4 (Table 14). Following a 2-6 hour retention in the primary pond the waste is neutralized as it flows to the secondary treatment ponds.

Storage tests (Table 14) showed that coliform concentrations were low in pH 3.8-4.0 primary effluents and were reduced to less than 100/100 ml within 24 hours at 2° C.

Circumstantial evidence indicates that coliform concentrations in mill secondary effluent can be reduced by limiting their concentration going into the ponds. Acidification and retention stages to kill coliforms in secondary influent were demonstrated in small scale and mill systems. It was further shown that this reduced coliforms in

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*See Glossary.

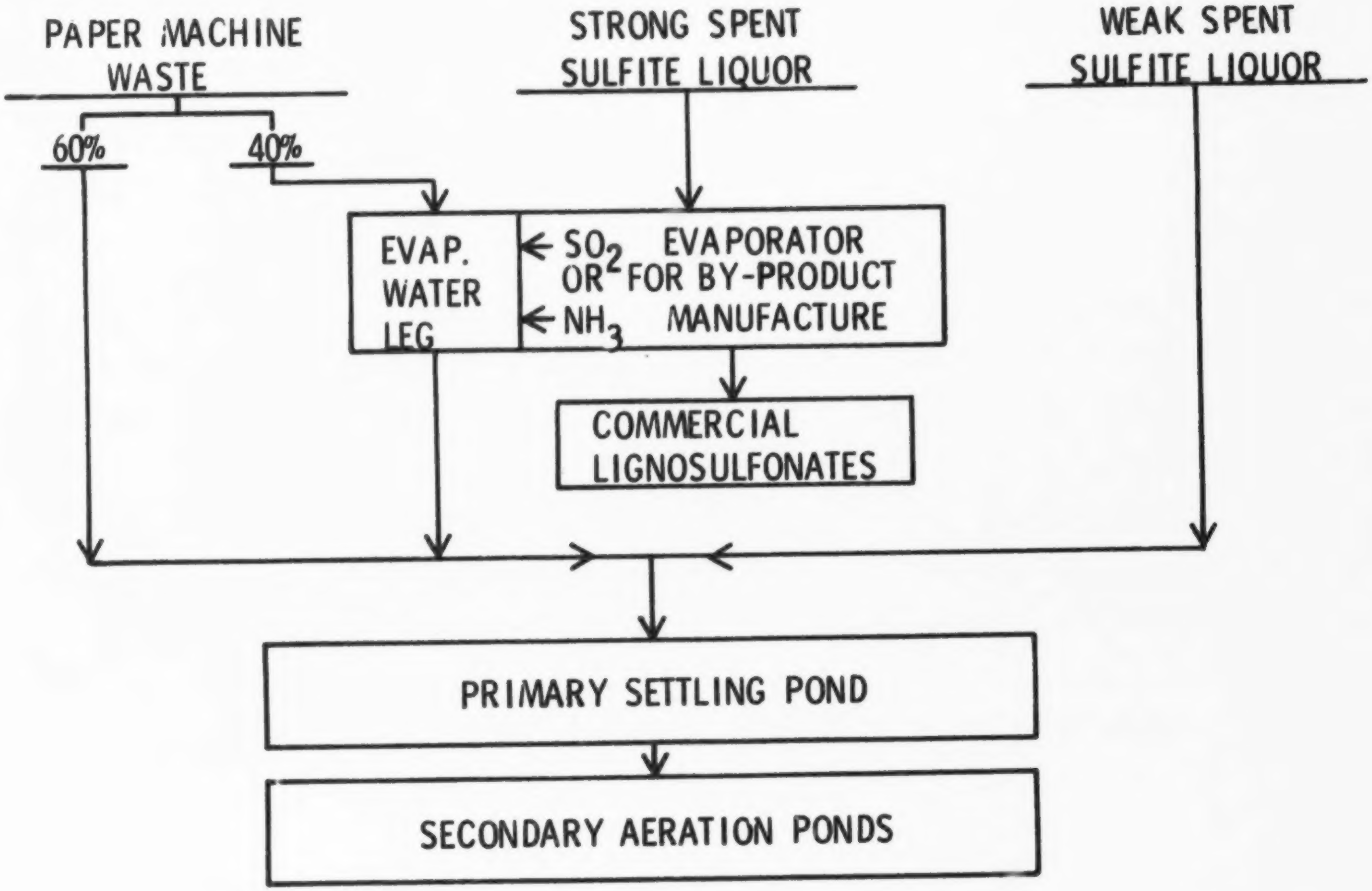

PAPER MACHINE WASTE
60%
40%
STRONG SPENT SULFITE LIQUOR
WEAK SPENT SULFITE LIQUOR
EVAP. WATER LEG
SO2 OR NH3
EVAPORATOR FOR BY-PRODUCT MANUFACTURE
COMMERCIAL LIGNOSULFONATES
PRIMARY SETTLING POND
SECONDARY AERATION PONDS

Figure 16. Flow of mill wastes.

Table 13. EFFECT OF BY-PRODUCT MANUFACTURE ON pH OF MILL WASTE USED IN EVAPORATOR"WATER LEG"[a]

By-product prod.			pH of mill waste							
Orzan^{R} grade	Approx. pH	# of samp.	Before"water leg"				After"water leg"			
			Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
AL	4	26	4.30	8.30	6.86	0.75	1.90	3.70	2.34	0.57
GL	4	42	5.80	9.80	7.25	0.82	2.10	3.60	2.65	0.41
KSL	7	28	5.90	10.20	7.61	1.02	6.50	9.80	7.90	0.93
LS	7	2	8.00	8.20	8.10	--[b]	7.80	8.30	8.05	--

[a] See glossary.

[b] -- Not calculated.

Table 14. EFFECT OF pH ON CONCENTRATIONS OF COLIFORMS IN MILL WASTES STORED AT 2° C.

Sample	pH		Coliforms/100 ml			Coliform red'n., %	
	Ini.	Adj.	Initial	24 Hrs.	48 Hrs.	24 Hrs.	48 Hrs.
Primary	9.0	--[a]	116×10^4	120×10^4	60×10^4	0	48
inf. (9/14/71)	9.0	7.0	30×10^4	121×10^4	165×10^4	0	0
Primary	3.8	--	39×10^2	< 100	< 100	> 97	> 97
inf. (9/16/71)	3.8	7.0	20×10^3	91×10^2	46×10^3	54	0
Primary	8.8	--	38×10^4	40×10^4	79×10^4	0	0
eff. (9/14/71)	8.8	7.0	20×10^4	78×10^5	76×10^5	0	0
Primary	4.0	--	67×10^2	< 100	< 100	> 98	> 98
eff. (9/16/71)	4.0	7.0	33×10^3	82×10^2	18×10^3	75	45
Secondary inf. (9/14/73)	8.7	--	43×10^4	27×10^4	30×10^5	37	0

[a] -- pH not adjusted.

effluent from small scale units. It was desired to demonstrate this last relationship in the mill systems but for the following reason this proved difficult:

Several types of lignosulfonates are produced. However, only with acidic grades are conditions established for significant coliform kill (Table 13). With alkaline grades, NH_3 rather than SO_2 is volatilized from evaporating spent sulfite liquor and the pH of mill wastes is increased (Tables 8, 14). High pH influents are relatively non-toxic to coliforms (Table 14). An attempt was made to maintain continuous production of acid by-products and to evaluate the effect on coliforms in secondary effluent. It was not successful because of unforeseen requirements for various products (Table 15).

Table 15. BY-PRODUCT EVAPORATOR OPERATING SCHEDULE

Date (Dec. 1971)	Percent of production time		
	Low pH products	High pH products	Not in operation
14	61	34	5
15	25	74	1
16	92	7	1
17	66	14	20
18	31	67	2
19	41	57	2
20	60	40	0
21	73	25	2
22	76	23	1
23	68	0	32
24	56	42	2
Mean	59	35	6

TEMPERATURE

Mean monthly temperatures of secondary effluent ranged from 13° C. in December 1971 to 29° C. during July and August of 1972 (Table I, Appendix). Mean coliform concentrations varied from month to month (Figure 17), however variations in counts for samples within a given month frequently exceeded the greatest difference between means of different months. Factors responsible for these individual variations would mask lesser effects due to temperature.

DISSOLVED OXYGEN

Aerated Basins

Measurements made on July 13, 1972, showed that secondary ponds were not completely mixed with respect to pH or dissolved oxygen concentrations (Figures 18 and 19). The possibility was investigated that coliform populations could be influenced by differences in oxygen content in poorly mixed locations within the ponds. Results obtained on Pond 1 samples, taken August 2, suggested that low D.O. concentrations favored coliform growth whereas high D.O. levels increased growth of other types of bacteria (Table 16). Coliforms comprised 11.5 percent of the total bacterial population in low D.O. ($<$ 0.3 ppm) samples and 4.2 percent for high ($>$ 2 ppm) D.O. samples. Variations in bacterial concentrations were less among low D.O. samples or among high D.O. samples than for the entire sampling. Similar results were found for Pond 2 but differences were slight (Table 17).

Small Scale System

At the end of the previous experiment with small scale equipment, on November 8, the control unit (No. 10) had a coliform concentration of 1.3 million cells/100 ml and the experimental unit (No. 9) had 6 thousand/100 ml (Table 12). The low coliform concentration was

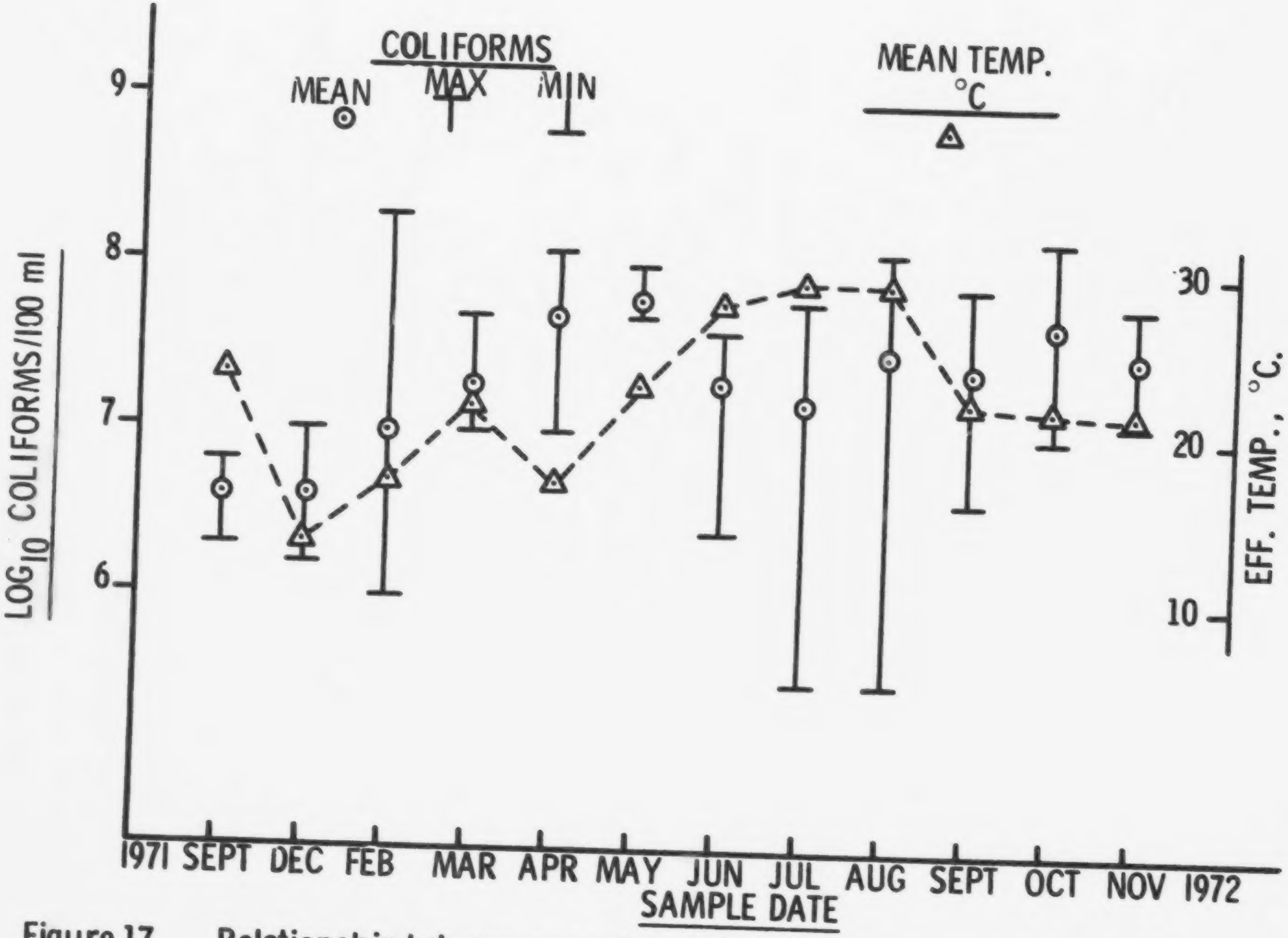


Figure 17. Relationship between secondary effluent temperature and coliform concentrations.

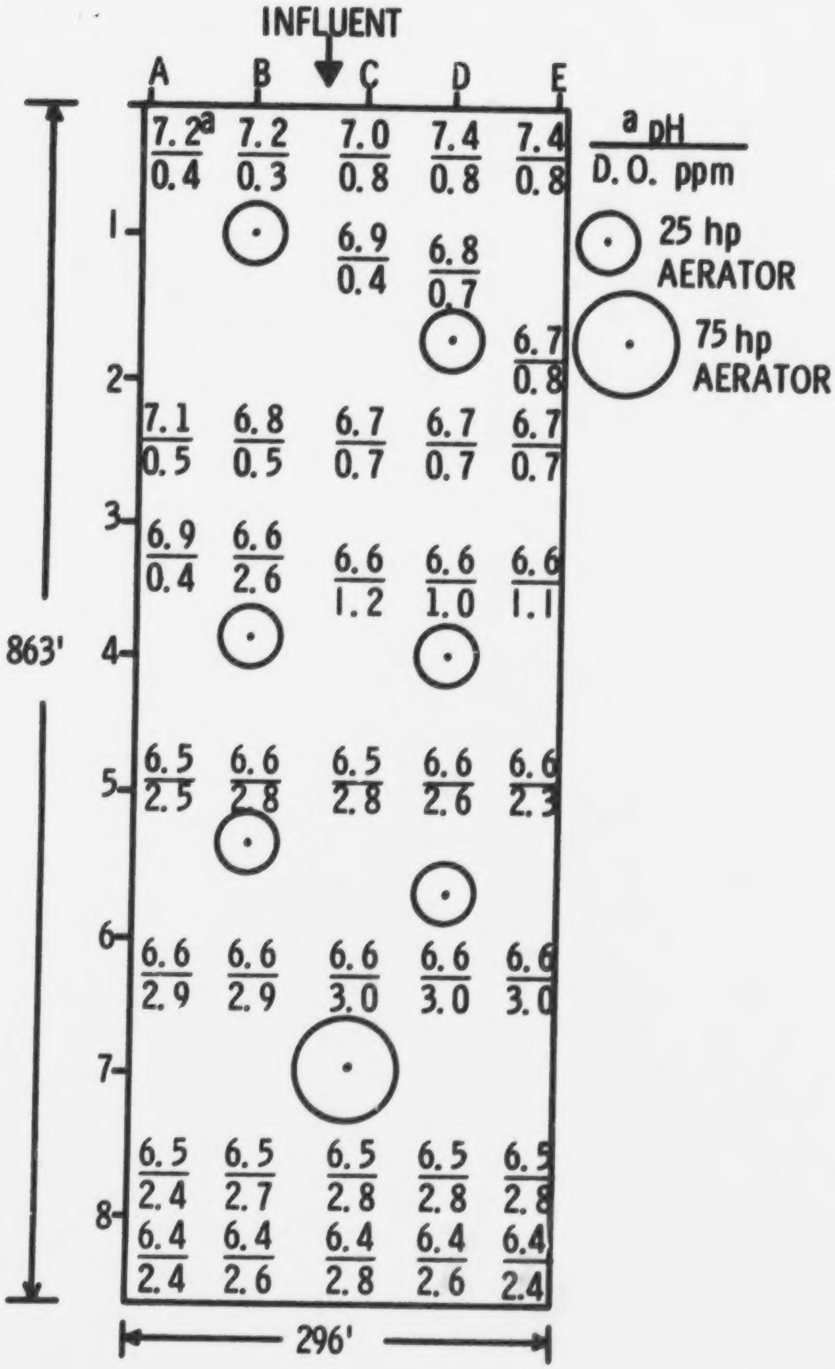
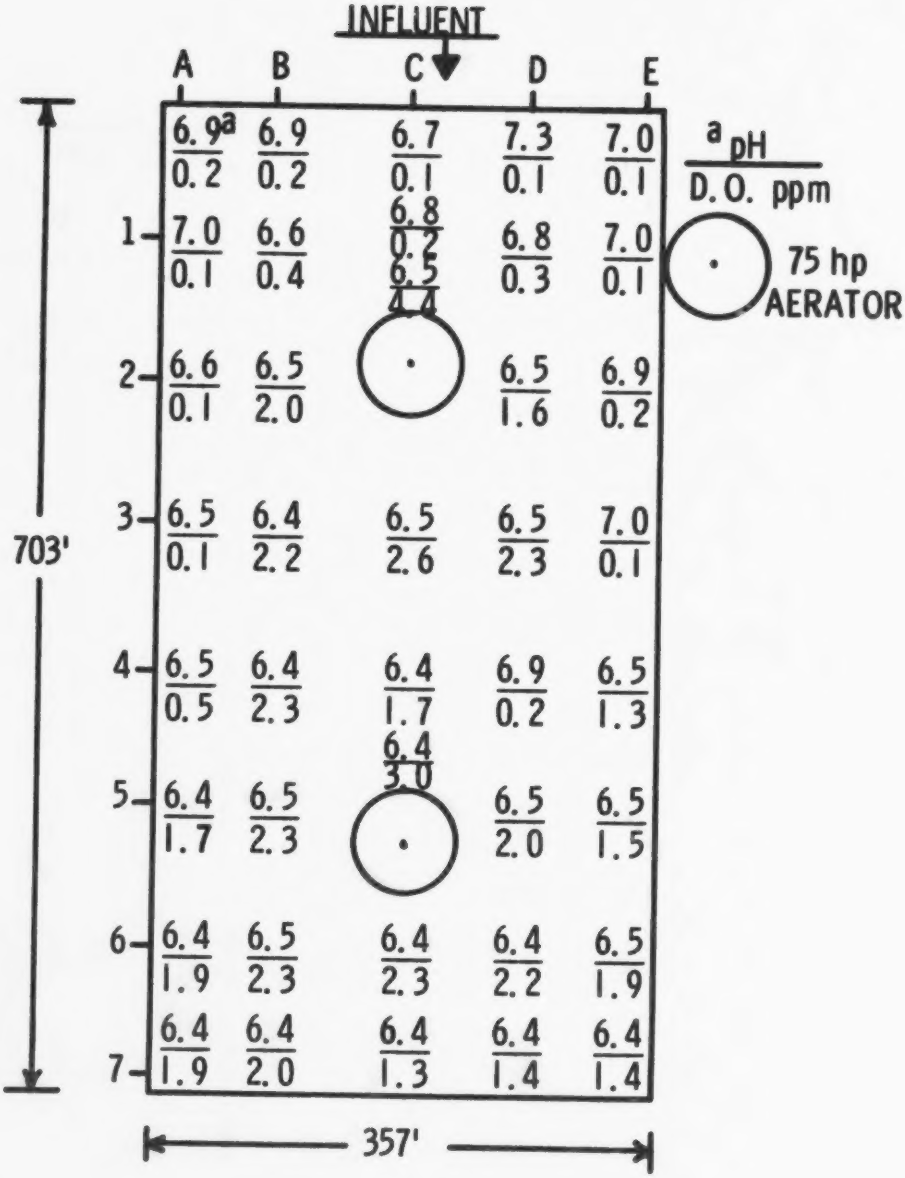

INFLUENT
A
B
C
D
E
7.2ᵃ / 0.4
7.2 / 0.3
7.0 / 0.8
7.4 / 0.8
7.4 / 0.8
ᵃ pH / D.O. ppm
25 hp AERATOR
75 hp AERATOR
1
6.9 / 0.4
6.8 / 0.7
6.7 / 0.8
2
7.1 / 0.5
6.8 / 0.5
6.7 / 0.7
6.7 / 0.7
6.7 / 0.7
3
6.9 / 0.4
6.6 / 2.6
6.6 / 1.2
6.6 / 1.0
6.6 / 1.1
863'
4
5
6.5 / 2.5
6.6 / 2.8
6.5 / 2.8
6.6 / 2.6
6.6 / 2.3
6
6.6 / 2.9
6.6 / 2.9
6.6 / 3.0
6.6 / 3.0
6.6 / 3.0
7
6.5 / 2.4
6.5 / 2.7
6.5 / 2.8
6.5 / 2.8
6.5 / 2.8
8
6.4 / 2.4
6.4 / 2.6
6.4 / 2.8
6.4 / 2.6
6.4 / 2.4
296'

Figure 18. Dissolved oxygen and pH of waste in Pond I.



	A	B	C	D	E
	$\frac{6.9^a}{0.2}$	$\frac{6.9}{0.2}$	$\frac{6.7}{0.1}$	$\frac{7.3}{0.1}$	$\frac{7.0}{0.1}$
1	$\frac{7.0}{0.1}$	$\frac{6.6}{0.4}$	$\frac{6.8}{0.2}$ $\frac{6.5}{4.4}$	$\frac{6.8}{0.3}$	$\frac{7.0}{0.1}$
2	$\frac{6.6}{0.1}$	$\frac{6.5}{2.0}$		$\frac{6.5}{1.6}$	$\frac{6.9}{0.2}$
3	$\frac{6.5}{0.1}$	$\frac{6.4}{2.2}$	$\frac{6.5}{2.6}$	$\frac{6.5}{2.3}$	$\frac{7.0}{0.1}$
4	$\frac{6.5}{0.5}$	$\frac{6.4}{2.3}$	$\frac{6.4}{1.7}$	$\frac{6.9}{0.2}$	$\frac{6.5}{1.3}$
5	$\frac{6.4}{1.7}$	$\frac{6.5}{2.3}$	$\frac{6.4}{3.0}$	$\frac{6.5}{2.0}$	$\frac{6.5}{1.5}$
6	$\frac{6.4}{1.9}$	$\frac{6.5}{2.3}$	$\frac{6.4}{2.3}$	$\frac{6.4}{2.2}$	$\frac{6.5}{1.9}$
7	$\frac{6.4}{1.9}$	$\frac{6.4}{2.0}$	$\frac{6.4}{1.3}$	$\frac{6.4}{1.4}$	$\frac{6.4}{1.4}$

Figure 19. Dissolved oxygen and pH of waste in Pond 2.

Table 16. EFFECT OF DISSOLVED OXYGEN CONCENTRATION ON BACTERIA IN POND 1

Sample point[a]	Total sampling				Low D.O. samples				High D.O. samples			
	D.O., ppm	Bacteria/100 ml		Colif. %	D.O., ppm	Bacteria/100 ml		Colif., %	D.O., ppm	Bacteria/100 ml		Colif., %
		Total X 10^7	Colif. X 10^6			Total X 10^7	Colif. X 10^6			Total X 10^7	Colif. X 10^6	
C - 0.5	0.15	182	180	9.9	0.15	182	180	9.9	--[b]	--	--	--
B - 0.5	0.30	153	175	11.4	0.30	153	175	11.4	--	--	--	--
C - 2.5	0.10	156	204	13.1	0.10	156	204	13.1	--	--	--	--
C - 3.5	0.75	198	106	5.4	--	--	--	--	--	--	--	--
C - 6.0	2.50	325	114	3.5	--	--	--	--	2.5	325	114	3.5
D - 6.2	3.40	244	120	4.9	--	--	--	--	3.4	244	120	4.9
C - 7.5	2.50	217	88	4.1	--	--	--	--	2.5	217	88	4.1
Mean	1.67	211	141	7.5	0.20	186	164	11.5	2.8	262	107	4.2
S.D.	1.41	60	44	3.9	0.11	16	16	1.6	0.52	56	17	0.70
Var., %	84	28	31	52	55	9	10	14	19	21	16	17

[a] Refers to coordinates in Figure 18.
[b] -- Not measured or calculated.

Table 17. EFFECT OF DISSOLVED OXYGEN CONCENTRATION ON BACTERIA IN POND 2

	Total sampling				Low D.O. samples				High D.O. samples			
		Bacteria/100 ml				Bacteria/100 ml				Bacteria/100 ml		
Sample point[a]	D.O., ppm	Total X 10^7	Colif. X 10^5	Colif., %	D.O., ppm	Total X 10^7	Colif. X 10^6	Colif., %	D.O., ppm	Total X 10^7	Colif. X 10^6	Colif., %
C - 6.8	0.30	282	90	3.2	0.30	282	90	3.2	--[b]	--	--	--
C - 6.0	2.10	276	94	3.4	--	--	--	--	2.10	276	94	3.4
C - 4.8	2.10	268	60	2.2	--	--	--	--	2.10	268	60	2.2
C - 3.5	2.10	234	100	4.3	--	--	--	--	2.10	234	100	4.3
C - 3.0	1.90	233	92	3.9	--	--	--	--	--	--	--	--
C - 1.5	1.70	214	172	8.0	--	--	--	--	--	--	--	--
C - 0.8	0.60	182	116	6.4	--	--	--	--	--	--	--	--
E - 0.2	0.20	213	150	7.0	0.20	213	150	7.0	--	--	--	--
C - 0.2	0.10	191	126	6.6	0.10	191	126	6.6	--	--	--	--
Mean	1.23	233	111	5.0	0.20	229	122	5.6	2.10	259	85	3.3
S.D.	0.90	36	34	2.0	0.10	47	30	2.1	0	22	22	1.1
Var., %	73	15	31	40	50	21	25	38	0	8	26	33

[a] Refers to coordinates in Figure 19.

[b] -- Not determined or calculated.

achieved by reducing their numbers in the influent to unit No. 9. Both units remained aerobic during this test but D.O. levels fluctuated (Table III, Appendix) and differences in coliform levels between the two units could not be related to differences in D.O.

In this trial new conditions were established to evaluate oxygen effects. Influent acidification stages were eliminated so that both aeration units received coliforms in settled influent. Aeration to unit 10 was increased to determine if a high concentration of D.O. could reduce the coliform population. A relatively low D.O. level was maintained in unit 9 to determine if the initially low coliform population would be stable under conditions simulating those present in the large aeration basins.

Throughout the experimental period from November 8-21, D.O. in unit 10 was between 7 and 8 ppm. In unit 9 it was maintained at 1-2 ppm until November 19 when its recirculation pump failed. Although the coliform concentration in unit 9 was very low at the start of the experiment, within 4.8 days it greatly increased and exceeded that found in the highly aerated unit (Table 18). These results and those obtained after 7.7 days of operation indicate that dissolved oxygen does have an effect on coliform populations. Low D.O. levels stimulate growth and/or high levels repress growth. More likely, high D.O. levels stimulate other microorganisms which grow better at low nutrient levels and may inhibit coliform growth or are predators upon them.

After 12.8 days of operation, coliforms in the highly aerated unit had dropped to 400 thousand/100 ml. This is a very low concentration compared to values obtained from analyses of numerous mill secondary effluent samples (Table 5). Unfortunately comparisons could not be made with the low D.O. unit because of its recirculation pump failure. However, the coliform concentration in the small highly aerated unit

Table 18. EFFECT OF DISSOLVED OXYGEN CONCENTRATION ON BACTERIA IN SMALL SCALE AERATION UNITS

Elaps. time days	D.O., ppm		Total bact./100 ml X 10^7			Colif./100 ml X 10^5			Colif., % of total		
	Small unit		Small unit		Mill sec. eff.	Small unit		Mill sec. eff.	Small unit		Mill sec. eff.
	9	10	9	10		9	10		9	10	
0	2.0	8.0	110	150	240	0.06	13	620	<0.001	0.09	2.6
1.9	2.2	7.9	--[a]	--	--	--	--	--	--	--	--
4.8	1.2	8.0	2400	1100	880	230	94	200	0.10	0.09	0.23
7.7	1.2	7.4	300	680	200	36	13	60	0.12	0.02	0.30
9.8	1.7	8.4	--	--	--	--	--	--	--	--	--
12.8	--	7.7	--	1600	200	--	4	80	--	0.003	0.40

[a] -- Not determined or calculated.

was only 5 percent of that in mill secondary effluent while its total bacterial population was considerably greater (Table 18). This is another indication that highly aerobic conditions minimize, perhaps indirectly, the development of high coliform concentrations in secondary treatment units.

In this experiment and the preceeding one with small scale equipment, and over extended periods in the mill treatment system, coliform concentrations in influent samples exceeded those found in effluent samples (Table 19). The problem with coliforms appears not to be one of growth in secondary aeration basins but rather one of minimizing inoculation of the ponds with coliforms and in establishing conditions which favor coliform antagonists or predators. High D.O. levels appear to help with the latter.

EPA Unit*

The combination of high D.O. levels and low coliform populations was found in another system. This was in a small unit located at the Lebanon mill and operated by personnel of the Environmental Protection Agency (EPA), Corvallis, Oregon. Retention time for this unit was approximately the same as for the large ponds but it differed in two other respects. Influent bypassed the primary pond and the aeration unit was operated at high D.O. levels. During a 40 day test period its mean D.O. concentration was 8.0 ppm ± S.D. 0.8 (Table 20). The mean concentrations of total bacteria and coliforms were 3,320 million/100 ml and 0.85 million/100 ml, respectively. Total bacterial populations were approximately the same as for the mill ponds during the same period but the mean coliform concentration was only about 2 percent of that found for mill effluent and most values were less than 0.1 percent. Coliform levels in the EPA unit were comparable to those found in the highly aerated small scale unit described earlier (Table 18).

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*See glossary.

Table 19. COMPARISON OF BACTERIAL CONCENTRATIONS IN SECONDARY INFLUENT AND EFFLUENT

Source of sample	Date	Number of samples				Total bact./100 ml X 10^7		Colif./100 ml X 10^5		Ratio of inf. to eff. bact.	
		Influent		Effluent							
		Total	Colif	Total	Colif	Inf.	Eff.	Inf.	Eff.	Total	Colif
	Sept. 1971	1	1	6	6	70	197	4	39	0.36	0.10
	Dec. 1971	5	6	6	7	9	132	20	37	0.07	0.54
Mill	March 1972	8	8	8	8	29	110	518	215	0.26	2.41
	April 1972	2	1	3	3	<1	104	1	533	<0.01	<0.01
Secondary	June 1972	8	8	8	11	26	503	272	217	0.05	1.25
	July 1972	0	7	3	12	--[a]	427	7	125	--	0.06
Treatment	Aug. 1972	5	10	5	9	16	564	953	335	0.03	2.84
	Sept. 1972	8	8	5	5	28	130	338	240	0.22	1.41
System	Oct. 1972	14	15	14	14	61	312	1590	483	0.20	3.29
	Nov. 1972	7	7	3	3	140	720	873	317	0.19	2.8
	Mean (Total)	(58)	(71)	(61)	(78)	46	355	686	266	0.04	2.1
Small Unit 9	Exp. 1, Oct. 6	13	13	12	12	0.58	402	2.1	3.5	0.001	0.60
Small Unit 10	to Nov. 8	10	10	13	13	225	419	1780	361	0.54	4.93
Small Unit 9	Exp. 2, Nov. 8	3	3	2	2	148	1350	627	133	0.11	4.71
Small Unit 10	to Nov. 21	3	3	3	3	148	1130	627	37	0.13	16.9

[a] -- Not determined or calculated.

Table 20. CONCENTRATION OF BACTERIA IN SECONDARY EFFLUENT FROM EPA UNIT AND MILL AERATION BASINS

Date (1972)	EPA unit D.O., ppm	Bacteria/100 ml				Ratio of bact. EPA:Mill	
		Total X 10^7		Colif. X 10^5			
		EPA	Mill	EPA	Mill	Total	Colif.
Oct. 10	8.7	230	360	1.2	520	0.64	0.002
11	9.6	410	310	2.4	260	1.32	0.009
16	7.3	100	240	30	770	0.42	0.039
19	7.7	860	210	42	440	4.10	0.095
24	8.0	160	320	10	240	0.50	0.042
26	7.3	590	600	2.0	370	0.98	0.005
31	9.1	290	640	0.3	230	0.45	0.001
Nov. 6	8.1	320	320	0.4	210	1.00	0.002
8	8.2	250	240	0.7	620	1.04	0.001
13	7.3	490	880	1.5	200	0.56	0.008
16	7.2	300	200	1.9	60	3.00	0.032
21	7.4	310	200	2.7	80	1.55	0.034
30	7.7	6	970	16	920	0.01	0.017
Mean	7.97	332	422	8.5	378	0.79	0.022
S.D.	0.76	221	264	13	264	1.22	0.027

Although high aeration rates reduced coliform concentrations in secondary aeration units, the order of magnitude was not great enough to provide a practical coliform control method.

Sediments

In the absence of dissolved oxygen, coliform concentrations became extremely high in the settling stages of the small waste treatment system. Mean concentrations were 9.3 billion and 4.35 billion per 100 ml in bottom samples from units 4 and 5 respectively (Table 21). A high concentration of 60 billion/100 ml was found on October 16. Although no D.O. measurements were made the lack of oxygen was attested to by strong H_2S odors in bottom samples and low, 0.1-0.3 ppm, D.O. levels measured at the upper surfaces of the settling units (Table III, Appendix).

Table 21. BACTERIAL CONCENTRATIONS IN SETTLING STAGES OF SMALL SCALE UNITS

Date	Total bacteria/100 ml X 10^7				Coliforms/100 ml X 10^5			
	Bottom samples		Top samples		Bottom samples		Top samples	
(1972)	Unit 4	Unit 5	Unit 4	Unit 5	Unit 4	Unit 5	Unit 4	Unit 5
Oct. 16	11,700	7300	360	290	600,000	140,000	11,000	9000
19	6,400	4400	330	290	56,000	62,000	1,100	1200
31	4,000	4000	100	110	33,000	24,000	1,500	1600
Nov. 6	2,700	3800	230	66	32,000	17,000	2,600	1400
8	5,500	2900	540	590	130,000	100,000	12,000	1000
13	1,100	1700	62	110	10,000	17,000	480	560
16	3,900	3700	550	280	10,000	51,000	560	2800
21	430	940	3	9	2,200	15,000	100	630
25	490	1200	5400	690	5,400	4,700	60,000	6400
30	1,100	150	65	1000	53,000	3,900	600	3100
Mean	3,730	3010	764	344	93,000	43,500	8,990	2770
S.D.	3,500	2110	1640	320	182,000	45,000	18,500	2800

Bacterial populations, including coliforms, in bottom samples were approximately 10 times greater than found in surface samples. This was probably not due to low D.O. per se but rather to the enriched environment at the bottom of the tank. Bacteria present in influent settle with fibers and increase in concentration through this process. In addition, autolysis of microorganisms would supply organic nitrogen and growth factors. The settled material also has a significant retention time whereas surface samples do not. The time required to produce the high concentrations of bacteria was not determined, however, they were present in the first bottom samples taken which was after 10 days of operation.

The development of coliforms in settled materials may be significant in mill operations. For example, sludge beds in the primary pond could contribute to the inoculation of the aeration basins and also protect bacteria within the interior against the toxic effect of periods of high acidity.

In secondary ponds, sludge beds form in quiescent areas and it is probably that their coliform concentrations are high. This would be an internal source of inoculum. Repositioning of aerators to disperse sludge might have the temporary effect of increasing coliform concentrations in the effluent. Occasional high coliform counts found in secondary effluent samples may have been due to resuspension of sludge.

There is a mill recycle system which is conducive to coliform development. Fibers from the primary pond sidehill screen, along with nutrients and coliforms in the associated liquid, are transported to the mill and stored in a large bin. Before the fibers are used, anaerobic conditions develop and coliforms increase. This will be discussed more fully in the section on Sources of Coliforms.

BOD

In August 1972, secondary effluent had some of the lowest and highest coliform concentrations found during the project (Table I, Appendix). During this period, influent BOD varied from 310 to 470 ppm but effluent BOD was relatively stable in the range of 65 to 95 ppm. There was no direct relationship between changes in BOD load to the secondary ponds and coliform concentrations in secondary effluent (Figure 20). Changes in coliform concentrations in secondary influent however, did correlate well with those occurring in secondary effluent. A similar situation was found in October 1972. Between the 13th and 18th, coliform concentrations increased from 29 million to 150 million/100 ml (Table I, Appendix). There was no significant change in influent or effluent BOD during the period but coliform concentrations in secondary influent increased from 29 million to 1.1 billion/100 ml (Table II, Appendix). These results again indicate that inoculation of secondary ponds with coliforms is the main factor which influences coliform concentrations in secondary effluent. The BOD of wastes being treated in secondary ponds can be changed by going from a parallel to a series operation. The effect that this has on coliforms is discussed in the following section.

SERIES VS PARALLEL POND OPERATION

A switch from parallel to series operation definitely changed several characteriatics of wastes within the ponds. However, no direct relationship could be established between the method of pond operation and coliform concentrations in the effluent.

Just prior to switching from parallel to series operation on November 16, coliform concentrations in Ponds 1 and 2 were 25 million and 6 million per 100 ml, respectively (Table 22). Higher concentrations also were found in Pond 1 after 3 days and 8 days of series operation.

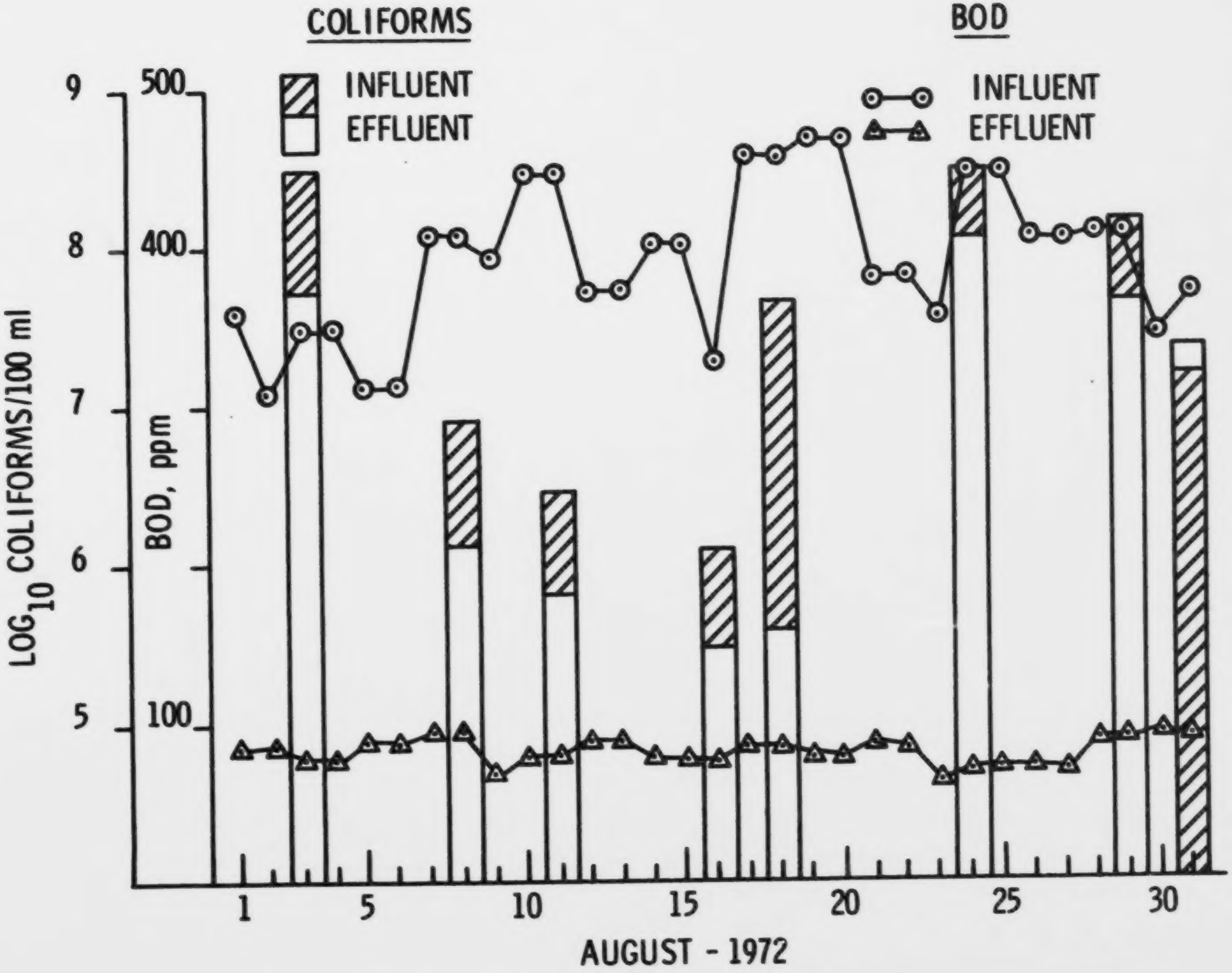

Figure 20. Relationship between BOD and coliform concentrations

Table 22. COMPARISON OF SECONDARY EFFLUENT CHARACTERISTICS FROM SERIES AND PARALLEL POND OPERATION

Analysis	Sample source	Mode of pond operation and date (Nov. 72)						
		Parallel			Series			Parallel
		6	8	13	16	21	25	30
	Pond 1	--[a]	--	7.0	7.5	7.4	7.3	7.2
pH	Pond 2	--	--	6.6	7.1	7.0	7.0	6.6
	Comb.	6.8	6.8	6.9	--	--	--	7.0
	Pond 1	--	--	21.9	24.4	25.7	25.0	19.8
Temp. °C.	Pond 2	--	--	21.3	20.8	21.2	18.4	19.7
	Comb.	20.0	20.4	21.6	--	--	--	19.8
	Pond 1	--	--	3.3	78.0	86.0	64.0	20.0
SO_3, ppm	Pond 2	--	--	3.3	2.4	3.0	4.7	4.0
	Comb.	4.3	3.7	3.2	--	--	--	7.9
	Pond 1	--	--	193	240	237	185	--
BOD, ppm	Pond 2	--	--	126	125	110	94	--
	Comb.	92	126	130	--	--	--	108
Total bact.	Pond 1	--	--	1900	300	280	43	380
per 100 ml	Pond 2	--	--	1400	200	200	470	1000
X 10^7	Comb.	320	240	1600	--	--	--	970
Coliforms	Pond 1	--	--	390	250	180	730	150
per 100 ml	Pond 2	--	--	80	60	80	1800	700
X 10^5	Comb.	210	620	120	--	--	--	920
Coliform Ratio--P1:P2		--	--	4.9	4.2	2.2	0.41	0.21

[a] -- Not determined.

Within the next 4 days, however, the situation reversed. Coliforms became more numerous in Pond 2 and their populations were greatly increased in both ponds. The sharp increase on November 25 was most likely caused by an increase in coliforms in influent (Figure 21). The reason for the reversal in relative coliform populations in the two ponds is more difficult to explain. It may have been unrelated to the method of operation as similar reversals have occurred during continuous parallel operation, e.g., July 31 to August 8 (Table IV, Appendix). It was apparent, however, that 12 days of continuous series operation did not reduce coliforms in secondary wastes to acceptable levels.

The following changes were related to the shift from parallel to series operation (Table 22):

Pond 1 became approximately 5° C. warmer because it received warm influent and was exposed to cold ambient air for a shorter time.

The BOD level in Pond 1 approximately doubled but stayed about the same in Pond 2.

Sulfite concentrations remained at 3 to 4 ppm in Pond 2 but increased to approximately 80 ppm in Pond 1. In other studies (Table 23) it was found that removal of $SO_3^=$ from mixtures of secondary influent and effluent was related to microbiological oxidation. From the determined oxidation rate of 1.34 ppm/hr ($SO_3^= \longrightarrow SO_4^=$) and the mean $SO_3^=$ concentration in influent of 142 ppm (Table 8) it can be calculated that approximately 4.3 days would be required for the complete oxidation. The increase in $SO_3^=$ in Pond 1 during series operation was probably due to its insufficient retention time of 2.5 days. On the basis of oxygen uptake rates, the relatively high $SO_3^=$ levels in Pond 1 had no adverse effect on microorganisms (Table 24, Figure 22). In fact, the rate of

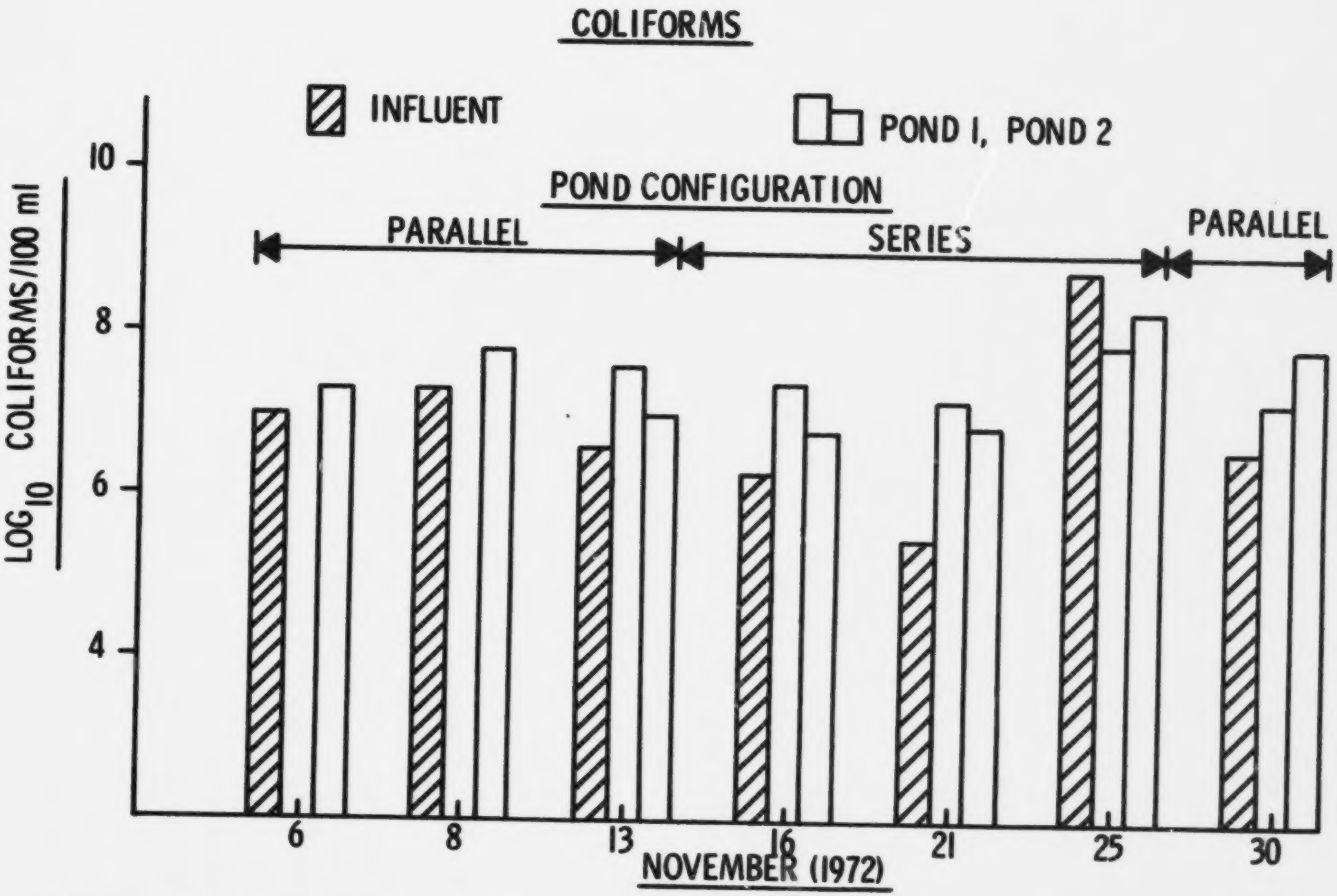

Figure 21. Coliform concentrations during series and parallel pond operation.

Table 23. OXYGEN UPTAKE AND SULFITE OXIDATION BY MIXTURES OF SECONDARY INFLUENT AND EFFLUENT

Sample and analysis made	Values for reaction times of:							
	Initial	1 Hr.	2 Hrs.	3 Hrs.	4 Hrs.	6 Hrs.	7 Hrs.	10.5 Hrs.
D.O., ppm								
Unheated sample	9.4	7.5	5.5	3.8	1.6	0.4	0.2	--[a]
Heated sample	9.4	9.4	9.2	9.0	8.7	8.3	8.1	--
Sulfite, ppm								
Unheated sample	81.8	81.3	80.4	78.4	77.4	74.0	72.5	67.6
Heated sample	55.4	54.4	53.9	54.4	54.4	52.4	51.9	50.0
Total D.O. uptake, ppm								
Unheated sample	--	0.9	3.9	5.6	7.8	9.0	9.2	--
Heated sample	--	0	0.2	0.4	0.7	1.1	1.3	--
Total $SO_3^=$ oxid., ppm								
Unheated sample	--	0.5	1.4	2.4	3.4	7.8	9.3	14.2
Heated sample	--	1.0	1.5	1.0	1.0	3.0	3.5	5.4
D.O. uptake, ppm/hr.								
Unheated sample	--	0.9	2.0	1.7	2.2	0.6	0.2	--
Heated sample	--	0	0.2	0.2	0.3	0.2	0.2	--
$SO_3^=$ oxid., ppm/hr.								
Unheated sample	--	0.5	0.9	2.0	1.0	1.7	1.5	1.4
Heated sample	--	1.0	0.5	-0.5	0	1.0	0.5	0.5
Effect of heating on:								
D.O. uptake, % red'n.	--		90	88	86	--	--	--
$SO_3^=$ oxid., % red'n.	32	+50	45			41	67	64

[a] -- Not determined.

Table 24. OXYGEN UPTAKE BY SECONDARY EFFLUENT SAMPLES FROM SERIES AND PARALLEL OPERATION

Pond conf.	Sample source	BOD ppm	Dissolved oxygen, ppm after:						O_2, uptake, ppm hr.	Ratio O_2 uptake rate: BOD
			Ini.	15 Min.	30 Min.	1 Hr.	2 Hrs.	3 Hrs.		
Series for 8 days	Pond 1	285	8.20	6.30	4.55	1.30	0.40	0.15	6.90	0.024
	Pond 2	152	8.85	8.25	7.80	7.00	5.20	3.50	1.85	0.012
Parallel for 2 days following series operation	Pond 1	200	8.75	8.05	7.25	6.00	3.30	--[a]	2.75	0.014
	Pond 1	200	9.20	8.25	7.45	6.00	3.20	--	3.20	0.016
	Pond 2	109	9.40	8.90	8.30	7.60	6.20	--	1.80	0.017
	Pond 2	109	9.50	--	8.45	7.75	6.35	--	1.75	0.016

[a] -- Not determined.

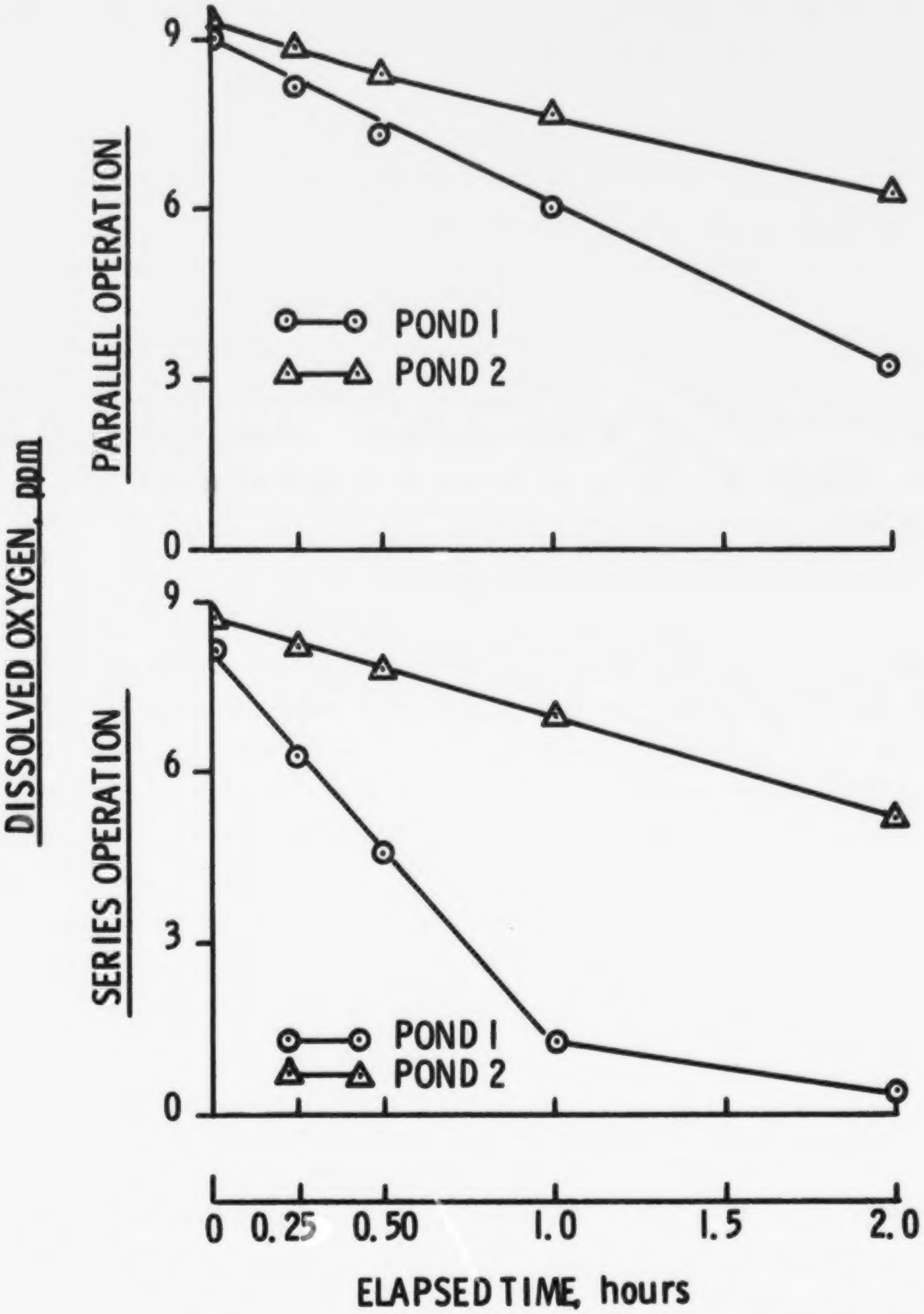

Figure 22. Oxygen uptake by secondary effluent from series and parallel pond operation.

oxygen uptake was greatest for Pond 1 effluent from series operation. This was due in part to a higher BOD concentration.

Microscopic observations showed that the shift to series operation caused a qualitative change in the microbial population. After 2 days of series operation, wet mounts of samples from Pond 2 showed 5 to 10 protozoa per field under 150x magnification compared to less than one per 10 fields in samples from Pond 1. Pond 2 samples also were distinguished by relatively high concentrations of small spheres which resembled in size and configuration the granules seen in large spirilla. Following a change back to parallel operation, the bacterial populations of the ponds became similar and protozoa disappeared from Pond 2 effluent.

RETENTION TIME IN SMALL SCALE SYSTEM

On November 21 influent flow to small aeration unit 10 was doubled. This reduced the retention time to 2.5 days which was equivalent to that of mill Pond 1 when in series configuration. At the start of the test, the coliform concentration was less than one million per 100 ml and was only 230,000 per 100 ml after 4 days. Levels increased to approximately 4 million/100 ml during the next 5 days. This was within the concentration range found earlier with a 5 day retention time (Table 25). Regardless of retention time, coliform levels in the effluent were consistently less than those in influent samples (Figure 23).

There were some interesting differences in the ways in which the small aeration unit and mill Pond 1 responded to reduced retention time (Table 26). After 9 days, the most significant differences were the large increase in $SO_3^=$ concentration, from 3.3 to 64 ppm, in Pond 1 and its high BOD of 185 ppm. During shorter retention BOD values for

Table 25. EFFECT OF RETENTION TIME ON CHARACTERISTICS OF EFFLUENT FROM SMALL SCALE UNIT

Analysis	Retention time and date (Nov. 1972)						
	5 Days					2.5 Days	
	6	8	13	16	21	25	30
pH	6.6	6.5	7.8	7.2	7.2	6.9	6.4
Temp. °C.	20.5	19.8	22.6	24.0	23.8	23.9	20.0
SO_3, ppm	2.6	2.5	3.0	2.9	2.8	4.5	2.9
BOD, ppm	69	57	78	104	87	73	109
D.O., ppm	2.8	4.4	8.0	7.4	7.7	8.2	8.2
Total bact. per 100 ml X 10^7	870	150	1100	680	1600	2800	2900
Coliforms per 100 ml X 10^5	120	13	94	13	4	2.3	36
Colif., % of total bact.	0.14	0.09	0.09	0.02	0.003	0.001	0.12

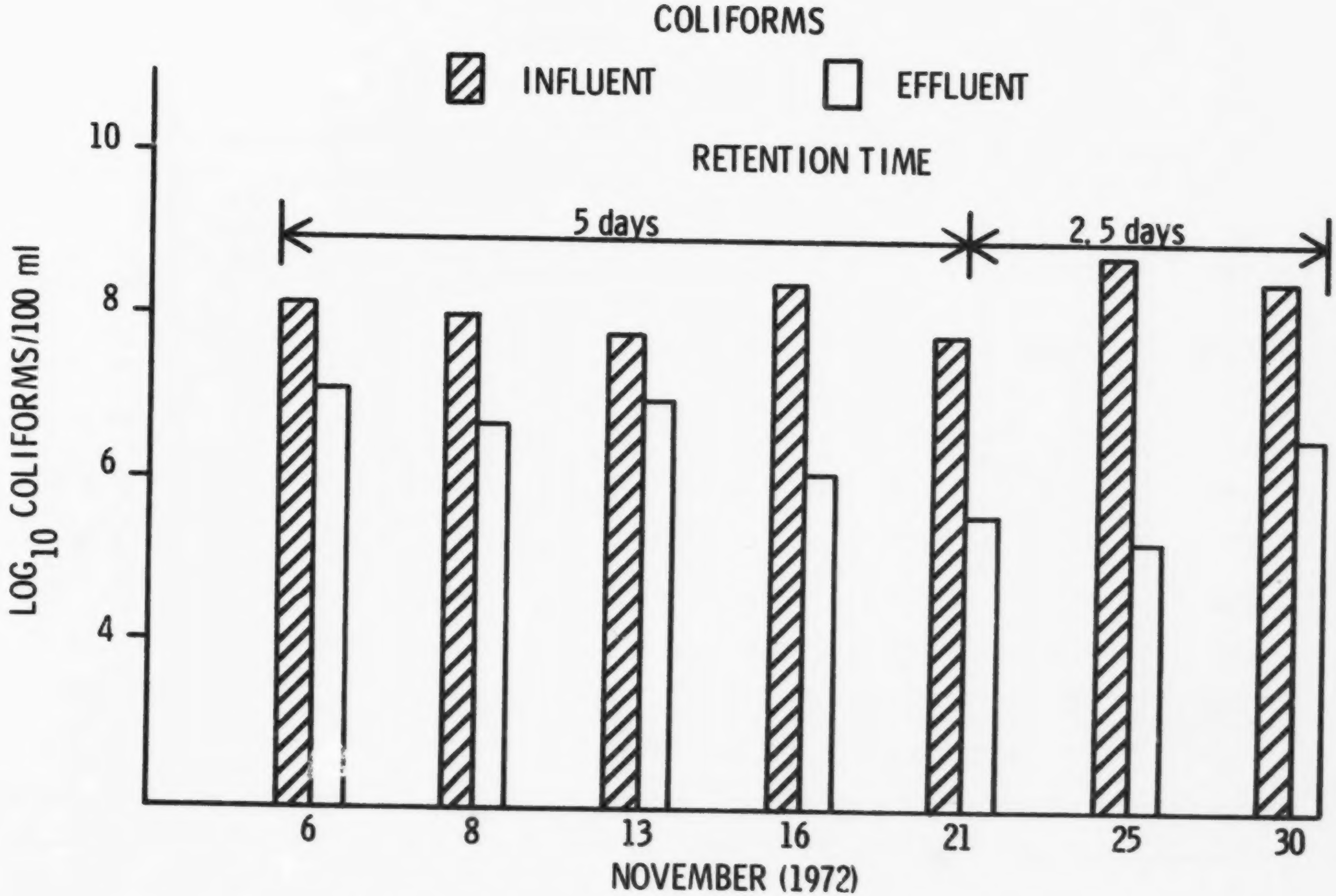

Figure 23. Effect of retention time on coliform concentrations in small scale treatment units.

Table 26. EFFECT OF RETENTION TIME ON CHARACTERISTICS OF EFFLUENTS FROM SMALL SCALE AND MILL AERATION UNITS

Measurement and treatment unit	Retention time, days		Change during reduced retention[a]	
	5	2.5	Units	Percent
pH				
Pond 1	7.0	7.3	+ 0.3	--[b]
Small unit	7.2	6.4	- 0.8	--
Temp, °C.				
Pond 1	21.9	25.0	+ 3.1	--
Small unit	23.8	20.0	- 3.8	--
SO_3, ppm				
Pond 1	3.3	64.0	+60.7	+1800
Small unit	2.8	2.9	+ 0.1	+ 4
BOD, ppm				
Pond 1	193	185	- 8	- 4
Small unit	87	109	+22	+ 25
D.O., ppm				
Pond 1	--	--	--	--
Small unit	7.7	8.2	0	0

[a] After 9 days of lower retention time.
[b] -- Not done or calculated.

Pond 1 reached 240 ppm (Table 22). In contrast $SO_3^=$ concentrations in the small unit remained at approximately 3 ppm and the BOD was still a relatively low 109 ppm. The ability to maintain good performance with only half the normal retention time was probably due to high D.O. concentration and complete mixing.

INTERACTIONS

In the preceeding sections attempts were made to evaluate the effect of single variables on coliforms. This proved difficult because of interrelationships among them. For example, as the BOD load to the secondary ponds increased from September to December 1971, temperatures of wastes within the ponds decreased. Some of the lowest influent BOD loads were found during June and July 1972. However, during the same period the ponds had the lowest pHs found during the entire project (Table I, Appendix).

Extremely high coliform concentrations were found in wastes devoid of dissolved oxygen (Table 21), but associated with this were extended storage times and relatively high BOD. Conversely, high D.O. levels in small scale units appeared to reduce coliform concentrations (Table 18), but BOD level could not be discounted as a contributing factor. The highly aerated unit had an average BOD of 91 ppm as compared to 148 ppm for the unit with normal aeration.

Overshadowing the importance of any other single variable or combination of variables was the effect of inoculation on the concentrations of coliforms in secondary wastes. The project mean coliform concentration for influent samples was considerably greater than for effluent samples (Table 10). By reducing the number of coliforms going into a small aerated unit, it was possible to reduce their concentration within the unit by several orders of magnitude (Table 12).

SECTION VIII

ROLE OF COLIFORMS IN BOD REDUCTION

Although coliforms represent less than 2 percent of the total bacterial population of the secondary treatment ponds (Table 5), it could be argued that they still are necessary to supply growth factors to other species or that BOD reducing activity is not related to bacterial concentration alone. Experiments with the small scale apparatus, however, showed that good BOD reduction could be obtained without high concentrations of coliforms. During the last two weeks of Experiment 1 (Table 12), good control was maintained over coliform concentrations in the influent going to experimental unit No. 9. This caused a corresponding decrease in coliforms within the unit to a mean of 86 thousand/100 ml compared to 10 million/100 ml for the control. Effluent samples from these units were analyzed for BOD by personnel of Crown Zellerbach (CZ) and the Environmental Protection Agency (EPA). Mean BOD values obtained by CZ were 86 ppm for Unit 9 and 69 ppm for Unit 10 (Table 27). This represents a 20 percent higher BOD for the unit which had lower coliform concentrations. EPA analyses gave mean values of 60 ppm and 61 ppm for units 9 and 10 respectively--essentially no difference. For comparison, mill grab samples taken on November 6 and 8 had BODs of 155 to 183 ppm and coliform concentrations of 20 million to 21 million per 100 ml.

Coliforms were not completely eliminated in the small experimental unit but they were reduced to the point which would allow the

Table 27. RELATIONSHIP BETWEEN COLIFORM CONCENTRATIONS AND BOD OF EFFLUENTS FROM SMALL SCALE SYSTEM

Date (1972)	Colif./100 ml X 10^5		Effluent BOD, ppm				Colif. ratio #9:#10	BOD ratio units 9:10	
			Unit #9		Unit #10				
	Unit #9	Unit #10	C.Z.	EPA	C.Z.	EPA		C.Z.	EPA
Oct. 26	0.240	140	100	64	76	67	0.0017	1.56	1.13
Oct. 31	0.029	130	78	53	74	61	0.0002	1.47	1.21
Nov. 6	0.014	120	105	67	69	60	0.0001	1.57	1.15
Nov. 8	0.060	13	60	55	57	55	0.0046	1.09	1.04
Mean	0.086	101	86	60	69	61	0.0009	1.43	1.13

following conclusion. If coliforms have any role in reducing the BOD of Lebanon wastes it can be satisfied by concentrations of less than 0.1 percent of those now found in the large ponds.

SECTION IX

SOURCES OF COLIFORMS

MILL SURVEYS

Several areas within the mill were evaluated as sources of coliforms. These bacteria were found in drains beneath paper machines but concentrations were low and they represented only a small fraction of the total bacterial population (Table 28). Of much greater importance were white water systems which utilized recirculated liquids.

Table 28. CONCENTRATIONS OF BACTERIA IN MILL DRAINS

Source of sample	Bacteria/100 ml Total X 10^7	Bacteria/100 ml Colif. X 10^5	Colif., % of total
#1 Paper machine, dry end	--[a]	0.002	--
#1 Paper machine, wet end	5.5	0.09	0.02
#2 Paper machine, wet end and pump well	3.2	0.02	0.006
Composite of beater room drains	7.7	0.29	0.038
Composite of all mill basement drains	1.0	0.009	0.009
Steam plant plus mill drains	1.2	0.005	0.004

[a] -- Not done.

RECYCLE SYSTEMS

In the high yield system there are several recycle loops but the most significant involved the screening bin. This bin receives low consistency pulp separated from the main mill sewer by a sidehill screen. The bin itself has a capacity of approximately 283 m^3 (10,000 cubic feet) and can be likened to a continuous growth chamber with a retention time of about 16 hours. Some of the key features of the recycle loop are illustrated in Figure 24. The liquid which is associated with the low consistency pulp is equivalent to primary influent and has a BOD of approximately 400 ppm. The major source of BOD is dilute spent sulfite liquor which also supplies ammonia nitrogen. Temperatures within the bin for most areas are between 20 and 30° C. and the pH is between 6 and 8. Under these favorable conditions, high concentrations of coliforms developed. The mean of 15 samples was 90 million coliforms per 100 ml. This represented 5.3 percent of the total population (Table 29). From the screening bin the pulp goes back to the mill where it inoculates fresh pulp with coliforms and contributes to the contamination of other production stages.

The production of regular sulfite pulp does not involve the screening bin. However, white water used in pulp washing and sluicing is recirculated (Figure 25) and coliform populations build up. A maximum of 8 million/100 ml was found in samples from the white water storage chest (Table 29). During surges, a portion of the white water overflows to the main sewer and is replaced with fresh make up water. Pulp is washed for four hours out of every six. Make up water however flows continuously. This tends to minimize bacterial buildup.

On the basis of coliform concentrations and flow rates, the two systems described represent major sources of coliforms going to the treatment ponds.

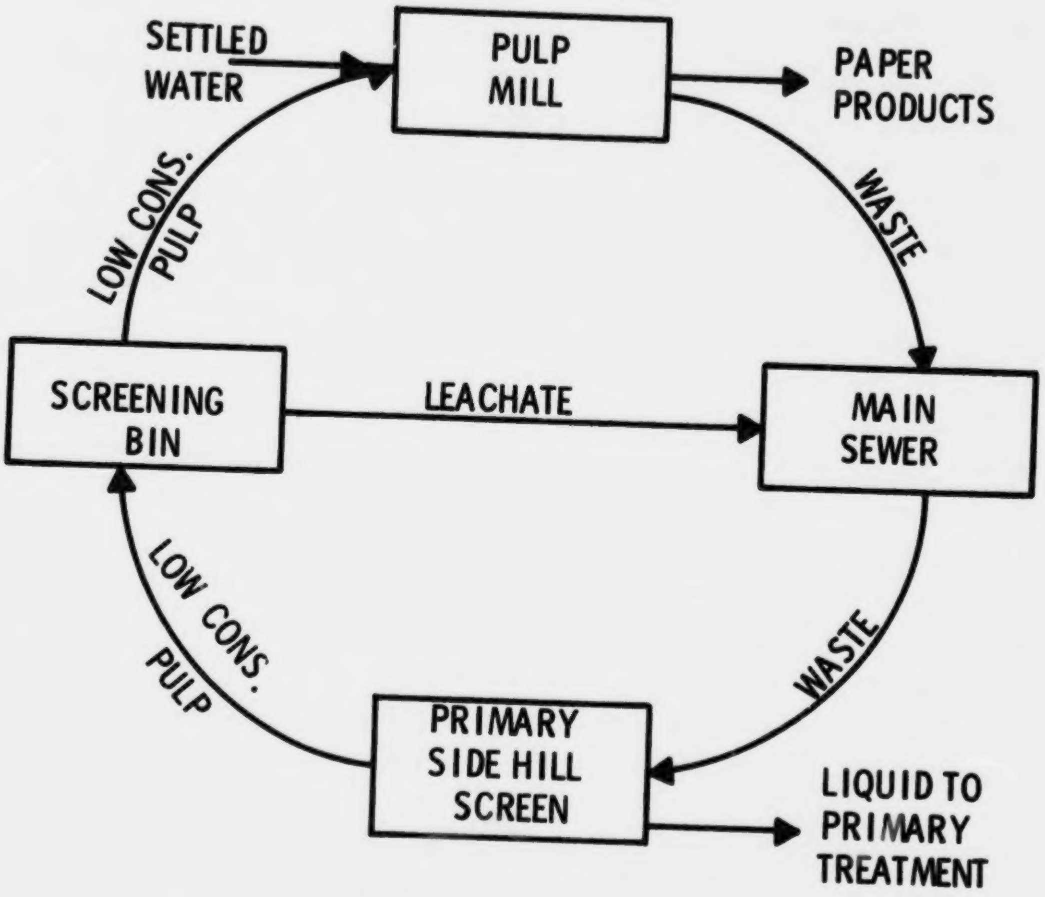
SETTLED WATER
PULP MILL
PAPER PRODUCTS
WASTE
LOW CONS. PULP
SCREENING BIN
LEACHATE
MAIN SEWER
WASTE
LOW CONS. PULP
PRIMARY SIDE HILL SCREEN
LIQUID TO PRIMARY TREATMENT

Figure 24. Recycle in high yield pulping system.

Table 29. CONCENTRATIONS OF BACTERIA IN MILL WHITE WATER AND TREATMENT SYSTEMS

Source of sample	Date (1972)	Bacteria/100 ml		Colif. % of total
		Total X 10^7	Colif. X 10^5	
Regular sulfite white water storage chest	March 23	2.3	0.19	0.08
	March 23	1.1	80	73
	Oct. 18	2.5	2.8	1.1
#3 Reg. sulfite stock chest	Oct. 18	51	0.11	0.002
Reg. sulfite, unscreened stock chest	Oct. 18	0.77	4.2	5.5
Reg. sulfite knotter	Oct. 18	0.08	0.044	0.55
Reg. sulfite decker	Oct. 18	0.32	0.055	0.17
Reg. sulfite Cowan screen	Oct. 18	2.5	2.0	0.80
Sidehill screen in screenings bin	March 23	15	38	2.5
	April 13	6	< 0.1	< 0.017
Screenings bin, North side	March 23	13	340	26
	Oct. 18	280	1700	6.1
Screenings bin, Northwest corner	Nov. 6	210	1800	8.6
Screenings bin, West side	March 23	29	740	26
	March 23	5.5	220	40
	Oct. 18	11	23	2.1
	Nov. 6	1700	2400	1.4
Screenings bin, Leachate	March 23	125	2500	20
	March 23	47	1540	33
	March 24	20	940	47
	March 24	18	260	14
	April 13	10	80	8.0
	April 13	16	60	3.7
	Oct. 18	55	900	16
	Nov. 6	7.7	1.0	0.13
High yield pulp storage chest sawdust	March 24	190	20	0.11
	April 13	10	0.10	0.01
High yield pulp storage chest chips	March 24	660	40	0.06
	April 13	50	< 1	< 0.02
Main sewer after scr. bin	March 24	13	50	3.8
	April 13	7.4	0.20	0.03
Secondary influent	March 24	180	4000	22
	April 13	0.03	< 1	< 33
Secondary effluent	March 24	50	340	6.8
	April 13	31	210	6.8

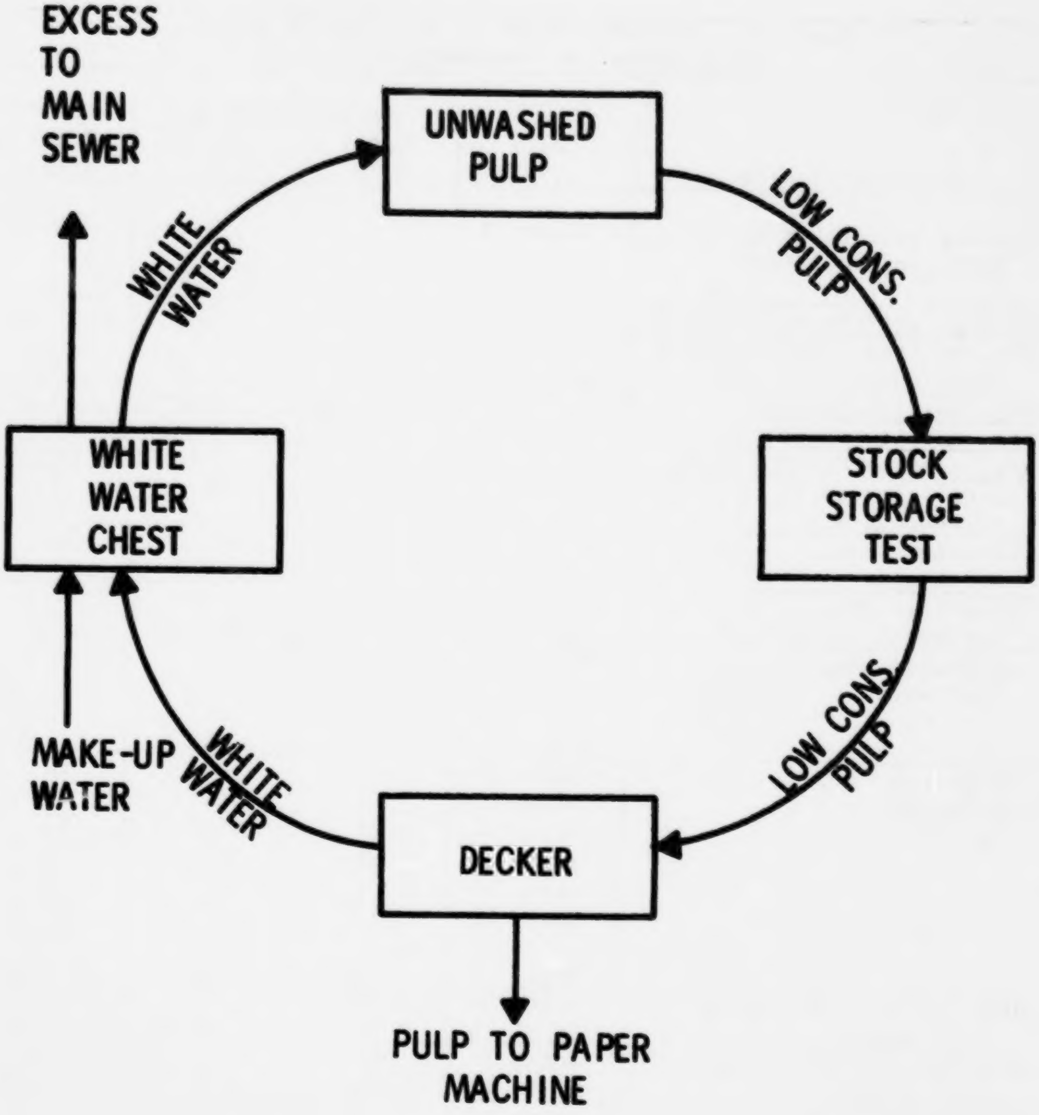
EXCESS TO MAIN SEWER
UNWASHED PULP
LOW CONS. PULP
WHITE WATER
WHITE WATER CHEST
STOCK STORAGE TEST
LOW CONS PULP
MAKE-UP WATER
WHITE WATER
DECKER
PULP TO PAPER MACHINE

Figure 25. Recycle in regular sulfite pulping system.

Coliforms enter the mill in the water supply. Although their concentrations are low (Table 30) they are a constant source of inoculum for the growth or recycle systems described.

Table 30. CONCENTRATIONS OF BACTERIA IN MILL WATER SUPPLY

Date (1972)	Water temp., °C.	Bacteria/100 ml		Colif., % of total
		Total X 10^4	Coliforms X 10^0	
Feb. 1	5.0	30	<100	<0.03
10	4.8	200	240	0.01
11	6.0	100	190	0.02
March 13	8.5	56	140	0.02
14	7.4	48	450	0.09
15	9.0	51	540	0.11
16	8.5	88	130	0.01
18	7.8	24	200	0.08
22	8.5	112	900	0.08
24	7.0	18	800	0.44
April 13	8.0	30	230	0.08
June 12	13.4	16	100	0.06
13	15.0	32	100	0.03
15	14.3	13	20	0.02
20	17.3	12	50	0.04
28	18.4	8	<10	<0.01
Oct. 18	12.0	11	1000	0.91

SANITARY WASTES

Tests also were made to determine if sanitary wastes were reaching the mill waste system. Rhodamine B dye was added to seven toilets which were flushed separately. Influent to the city treatment system was then monitored. Presence of the dye was considered to be positive evidence that sanitary waste from that source was not entering the mill waste treatment facility. This was a more satisfactory method than looking for the tracer in the mill waste. Here, negative results were inconclusive because of effluent masking effects and/or reactions with the dye. The tracer was found in only five trials. Breaks were located in lines from the two suspect toilets and it was found that wastes were being channeled to the primary pond sidehill screen. The toilets were barred from use until the defective lines were replaced on April 27. Elimination of these sources of coliforms did not reduce coliform concentrations in secondary influent or effluent (Tables I and II, Appendix).

SECTION X

ACTIVITY OF CHLORINE IN SECONDARY WASTES

INITIAL EVALUATION OF BACTERICIDAL ACTIVITY

Preliminary laboratory trials showed that 5 to 10 ppm chlorine in secondary effluent would greatly reduce coliform concentrations within 10 minutes. Similar activity was found in initial mill trials. Tests made on September 28, 1971, showed that 7 ppm chlorine killed 99.997 percent of the coliforms within 60 minutes (Table 31).

Table 31. EFFECT OF TIME ON DESTRUCTION OF BACTERIA BY CHLORINE. MILL TRIAL OF SEPT. 28 WITH 7 PPM CL.

Reaction time	Bacteria/100 ml X 10^5		Number of bact. killed/100 ml X 10^5		% of Initial population killed	
	Total	Colif.	Total	Colif.	Total	Colif.
0	49,000	33	0	0	0	0
1 Minute	5,200	1.6	43,800	31.40	89.388	95.152
5 Minutes	6,100	0.13	42,900	32.87	87.551	99.606
10 Minutes	5,700	0.029	43,300	32.97	88.367	99.912
30 Minutes	1,600	0.004	47,400	33.00	96.735	99.988
1 Hour	300	0.001	48,700	33.00	99.388	99.997
16 Hours	8,400	0.001	40,600	33.00	82.857	99.997

Action was rapid with over 95 percent kill in 1 minute. There also was significant reduction in the total bacterial population during the same period. There was some regrowth of the total population, but not of coliforms, between 1 and 16 hours after chlorination.

In another mill trial reaction times were kept at 10 minutes and the rate of chlorination was varied. Bactericidal activity was apparent at 5.3 ppm but 8.9-10.8 ppm were required for adequate coliform kill (Table 32).

Table 32. EFFECT OF CHLORINE CONCENTRATION ON DESTRUCTION OF BACTERIA. MILL TRIAL OF SEPT. 29.

Chlorine conc., ppm	Bact./100 ml after 10 minutes X 10^5		Number of bact. killed/100 ml X 10^5		% of Initial population killed	
	Total	Colif.	Total	Colif.	Total	Colif.
0	15,000	49.0	0	0	0	0
5.3	4,800	21.0	10,200	28.00	68.000	57.143
7.0	5,400	7.40	9,600	41.60	64.000	84.898
8.9	6,400	0.81	8,600	48.19	57.333	98.347
10.8	4,100	0.001	10,900	49.00	72.667	99.998

A large segment of the total population also was killed. Coliform data shown in Table 32 was obtained by the membrane filter method. The multiple tube presumptive test gave slightly higher results but also indicated that a chlorine concentration between 8.9 and 10.8 ppm was effective against coliforms (Figure 26).

Laboratory tests showed that chlorine reacts rapidly with Lebanon secondary effluent and the amount taken up within 5 minutes was proportional to that added, over a wide range of concentrations. This is illustrated in Figure 27. From the curve it would be difficult to assign a conventional chlorine demand value to the effluent as there is no sharp break between 2 and 40 ppm of added chlorine. In other tests the addition of 500 ppm chlorine to effluent resulted in residuals of 1 to 5 ppm after a 60 minute contact time. This indicates a chlorine demand of approximately 500 ppm which is many times greater than bactericidal concentrations.

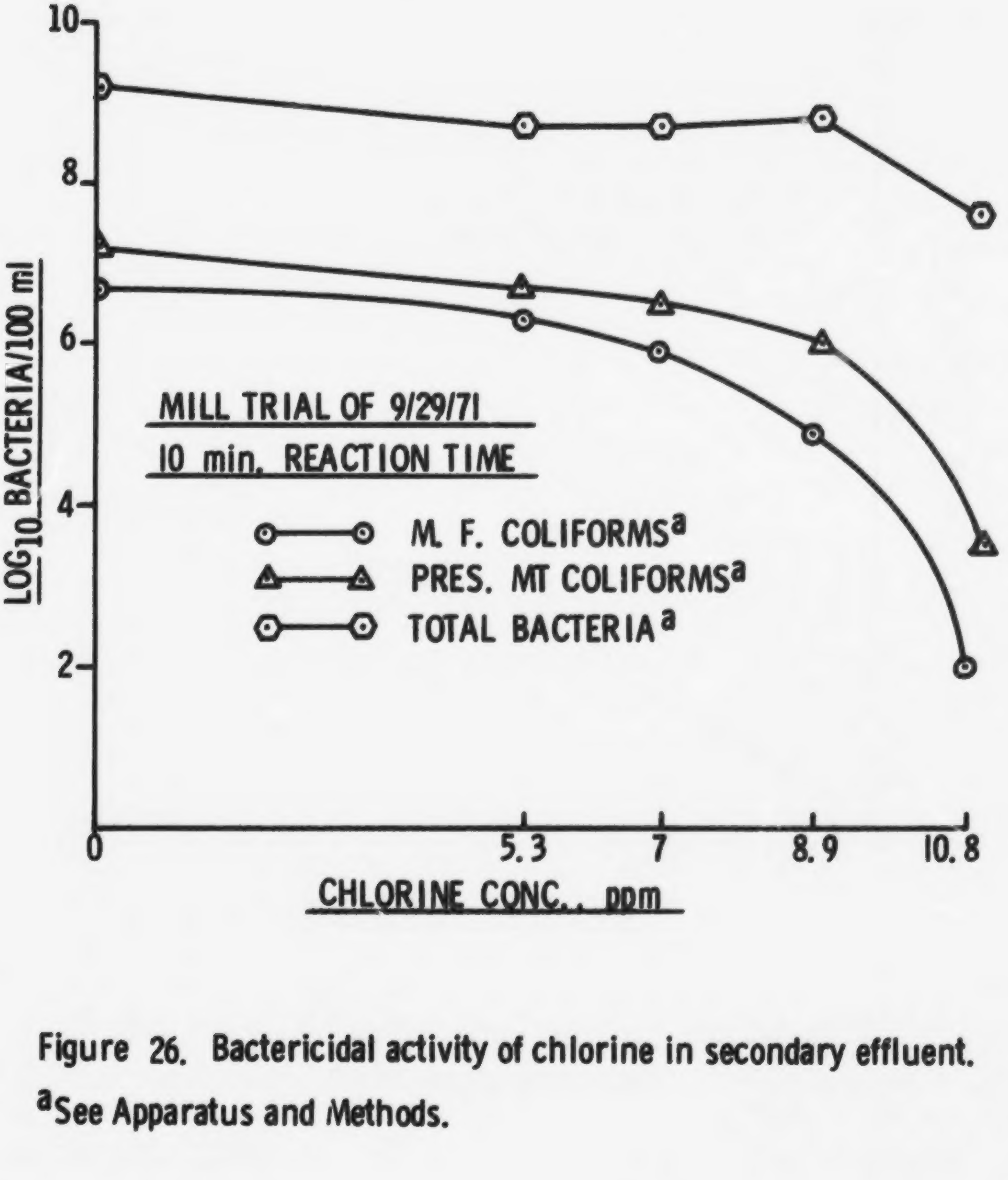

Figure 26. Bactericidal activity of chlorine in secondary effluent.
[a]See Apparatus and Methods.

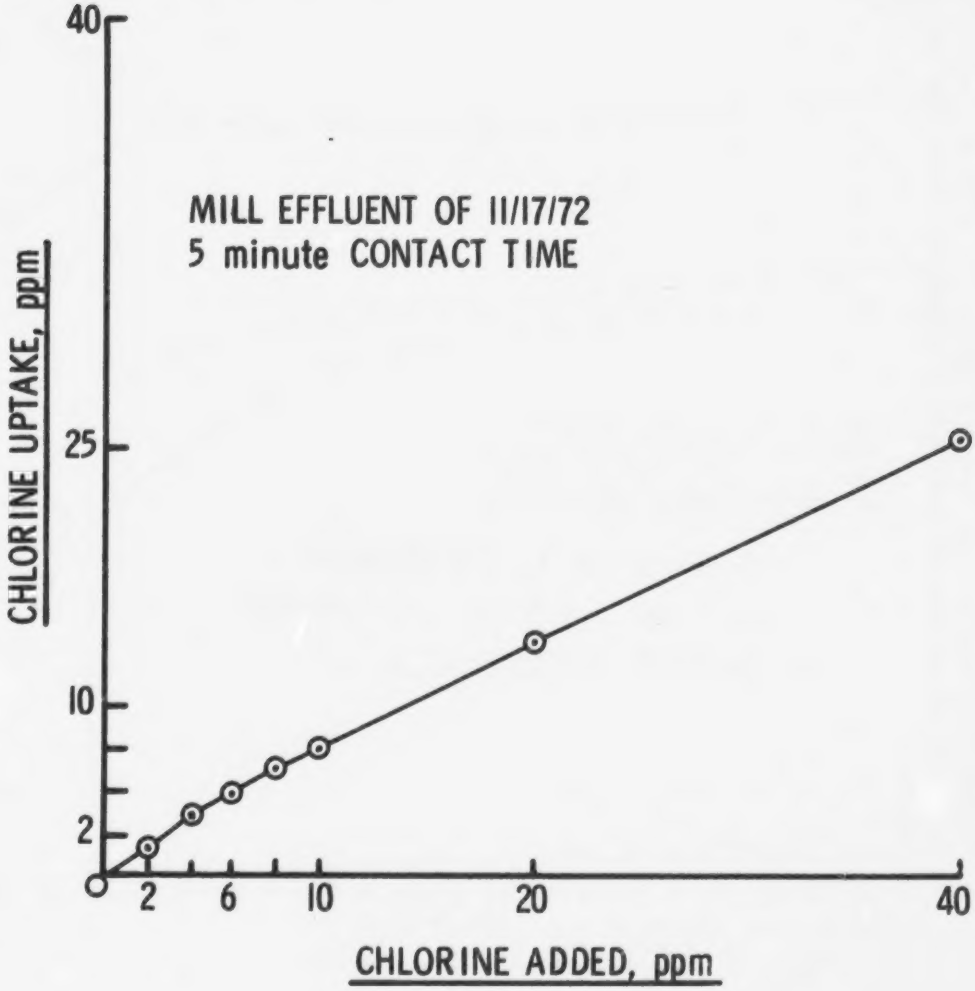

Figure 27. Chlorine uptake by secondary effluent. Laboratory chlorination.

EFFECT OF DILUTION

Secondary effluent is discharged into Mark Slough where it may be diluted by as much as 50 percent by water spilling over a dam above the slough. This suggested that chlorine treatments which were effective against coliforms in undiluted effluent might not be adequate when the effluent, and consequently the chlorine, were diluted. To evaluate the possibility, effluent was chlorinated at a rate of 9.1 ppm. A chlorinated sample was collected at the outfall to the slough. A portion of the sample was immediately diluted with an equal volume of water taken upstream from the outfall. The diluted and undiluted samples were incubated at 20° C. and analyzed at intervals for bacteria. It was found that coliform concentrations decreased at approximately the same rates in dilute and non-diluted chlorinated effluent samples (Figure 28). As in previous tests, approximately 90 percent of the coliform populations were killed within the first minute (Table 33). There was no significant regrowth of coliforms within 24 hours of chlorination.

Results from these initial experiments indicated that coliforms in secondary effluent could be controlled under existing field conditions by the addition of approximately 10 ppm chlorine. In succeeding trials, however, it became apparent that this was not a reliable method. On December 23 and 27, chlorine concentrations of 5 to 10 ppm were effective against coliforms but on the 14th, 15th, and 23rd, there was little or no activity at 9.0 to 15.0 ppm (Table 34). These variations in performance initiated a study to determine the effect of variables on chlorine activity.

METHODS FOR EVALUATING CHLORINE ACTIVITY

Three rapid methods were developed for estimating chlorine activity. They made it possible to analyze many more samples in a given time than could be done by conventional methods of coliform analysis.

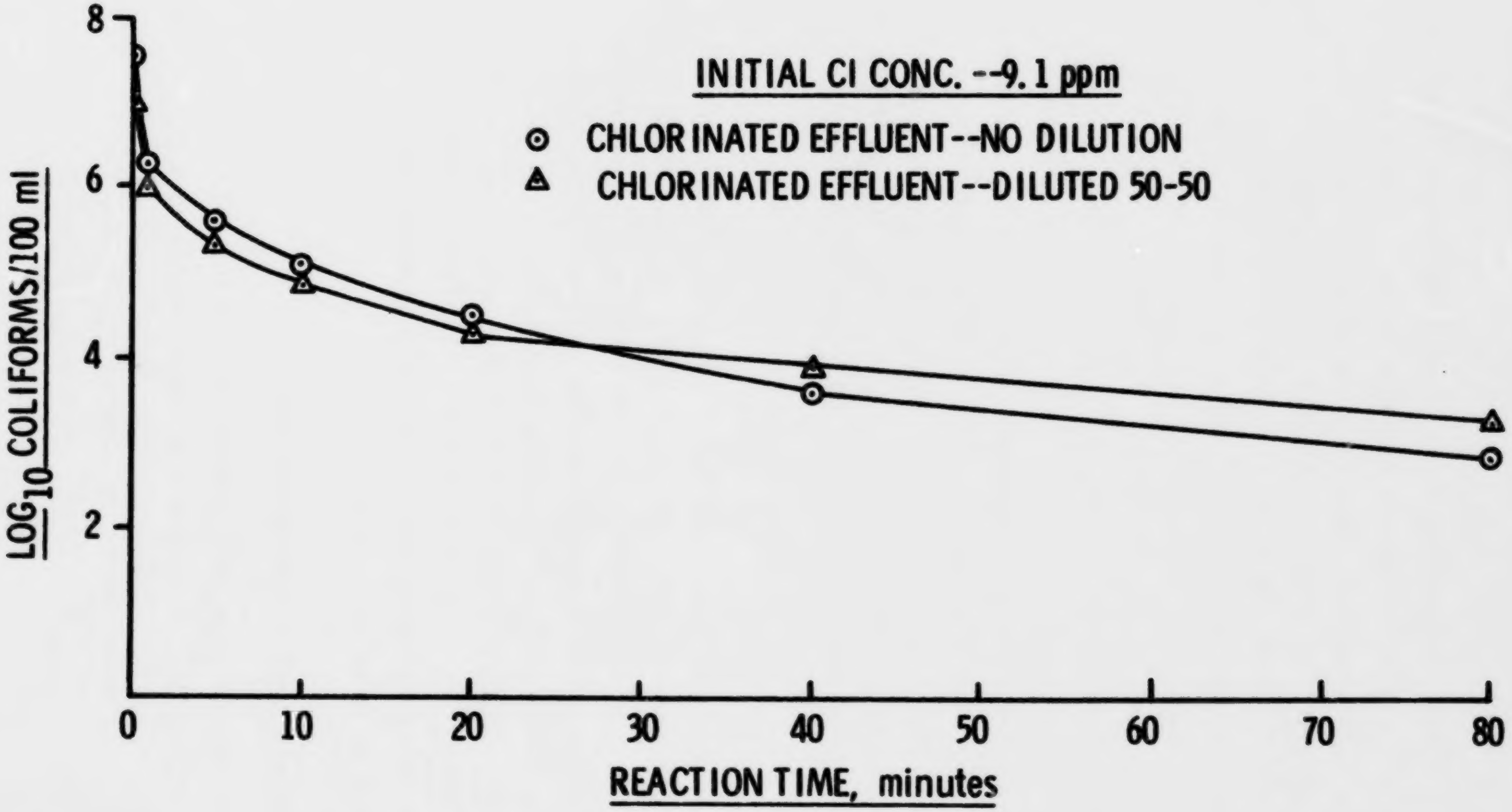

Figure 28. Effect of dilution on chlorine activity.

Table 33. EFFECT OF DILUTION ON THE BACTERICIDAL ACTIVITY OF CHLORINE IN SECONDARY EFFLUENT. MILL TRIAL OF 10-26-71 WITH 9.1 ppm INITIAL CHLORINE

	Colif./100 ml X 10^5		Coliforms killed				Total bact. per 100 ml X 10^7		Total bacteria killed			
			Cells/100 ml X 10^5		Percent				Cells/100 ml X 10^7		Percent	
React. time, mins.	Undil. eff.	Eff. dil. 1:2	Undil. eff	Eff. dil. 1:2	Undil. eff.	Eff. dil. 1:2	Undil. eff.	Eff. dil. 1:2	Undil. eff.	Eff. dil. 1:2	Undil. eff.	Eff. dil. 1:2
0	320	99	0	0	0	0	220	210	0	0	0	0
1	22	9.4	298	90	93.125	90.505	160	220	60	0	27.273	0
5	3.9	2.0	316	97	98.781	97.980	250	130	0	80	0	38.095
10	1.2	0.74	319	98	99.625	99.253	170	110	50	100	22.727	47.619
20	0.32	0.18	319+	98+	99.900	98.818	180	98	40	112	18.182	53.333
40	0.037	0.081	319+	98+	99.988	99.982	120	64	100	146	45.454	69.524
80	0.008	0.019	319+	98+	99.998	99.981	64	42	156	168	70.909	80.000
160	0.011	0.007	319+	98+	99.997	99.993	33	28	187	182	85.000	86.667
320	0.006	0.003	319+	98+	99.998	99.997	80	40	140	170	63.636	80.952
24 Hrs.	0.006	0.008	319+	98+	99.998	99.992	170	100	50	110	22.727	52.381

Table 34. EFFECTIVENESS OF MILL CHLORINATION SYSTEM

Date (1971)	Cl conc., ppm	Reaction time (min.)	Colif./100 ml X 10^5	Colif. redn., %
Dec. 14	0	0	16	0
	9.0	1	13	18.750
	9.0	5	16	0
	9.0	10	18	0
	9.0	20	14	12.500
Dec. 15	0	0	50	0
	3.0	10	60	0
	5.0	10	100	0
	7.0	10	80	0
	9.0	10	50	0
	11.0	10	50	0
	13.1	10	40	20.000
	15.0	10	40	20.000
Dec. 23	0	0	104	0
	2.7	30	51	50.962
	4.6	30	58	44.321
	10.5	30	< 0.1	> 99.904
	15.0	30	< 0.001	> 99.999
Dec. 27	0	0	54	0
	5.0	30	> 0.1	< 99.815
	10.0	30	< 0.001	> 99.998
Dec. 31	0	0	18	0
	7.8	30	14	22.222
	12.4	30	13	27.778

Perhaps of greater importance, cause and effect could be related in a very short interval of time. The methods proved to be very useful in evaluating the effects of variables on chlorine activity and for monitoring full scale chlorination of effluent.

Motility Test

Secondary effluent consistently contained motile spirilla (Figure 9). The concentrations of chlorine required to stop their motility was found to correlate well with those required to reduce coliforms to acceptable levels (Table 35). To carry out the test, chlorine was allowed to react for the desired length of time, then was inactivated with sodium thiosulfate. The concentration of motile spirilla remaining was estimated by examining the sample microscopically with phase contrast and 400 magnification. When motile spirilla were present, 20 fields were examined and the number per field estimated. If no motility was found within 20 fields an additional 80 fields were examined. If no motile spirilla were seen, their concentration was assumed to be 0 per field.

Inhibition of Oxygen Uptake

As microorganisms utilize various compounds in secondary wastes they consume approximately 2 ppm of oxygen per hour. Rates will vary depending on concentrations of substrates, oxygen, and microorganisms. The amounts of chlorine required to inhibit the rate of oxygen uptake, by 64 percent or more were similar to those required to kill coliforms (Table 35). The test was performed by transferring mechanically aerated effluents to BOD bottles and then measuring D.O. concentrations at intervals. A D.O. meter equipped with a stirring BOD probe was used for this purpose.

Table 35. COMPARISON OF METHODS FOR EVALUATING CHLORINE ACTIVITY. OXYGEN UPTAKE, BACTERIAL MOTILITY AND MEMBRANE FILTER

Mill trial date (1971)	Cl conc, ppm	Oxygen uptake test											Motility test				Colif 100 ml X 10^3 (M.F.)	Colif, red., %
		Dissolved oxygen, ppm						Inhib of O_2 uptake, %					Motile spirilla[b] after:					
		Ini	1 Hr	2 Hr	3 Hr	4 Hr	24 Hr	1 Hr	2 Hr	3 Hr	4 Hr	24 Hr	10 Min	15 Min	30 Min	24 Hr		
Dec. 23	0	9.8	7.0	4.8	2.4	0.7	0.7	0	0	0	0	0	1-10	1-10	1-10	1-10	104	0
	2.7	9.8	6.8	4.7	2.7	0.7	0.5	31	0	4	0	0	1-10	1-10	1-10	1-10	51	50.962
	4.6	9.8	6.7	4.4	2.2	0.5	0.4	0	0	0	0	0	1-10	1-10	1-10	1-10	58	44.321
	10.0	9.6	7.3	6.3	5.1	4.0	0.4	22	34	58	38	0	1-10	0.1-1	0.01-0.1	0.01-0.1	0.1	99.904
	15.0	9.5	8.5	8.1	7.8	7.5	--[a]	64	72	77	78	--	0.01-0.1	0.01-0.1	0	0	0.001	99.999
Dec. 27	0	10.3	7.4	5.0	2.6	0.4	0.2	0	0	0	0	0	1-10	1-10	1-10	1-10	54	0
	5.0	10.0	7.9	--	5.2	2.7	0.2	28	--	37	26	3	0.1-1	0.1-1	0.1-1	1-10	0.1	99.815
	10.0	10.0	9.0	--	7.7	6.9	2.1	65	--	70	69	22	0.01-0.1	0.01-0.1	0	0	0.001	99.998
Dec. 31	0	--	--	--	--	--	--	--	--	--	--	--	--	--	1-10	--	18	--
	4.0	--	--	--	--	--	--	--	--	--	--	--	--	--	1-10	--	--	--
	6.0	--	--	--	--	--	--	--	--	--	--	--	--	--	1-10	--	--	--
	7.8	--	--	--	--	--	--	--	--	--	--	--	--	--	1-10	--	14	22.222
	9.7	--	--	--	--	--	--	--	--	--	--	--	--	--	1-10	--	--	--
	12.0	--	--	--	--	--	--	--	--	--	--	--	--	--	1-10	--	13	27.778
	12.0	--	--	--	--	--	--	--	--	--	--	--	--	--	1-10	--	11	30.889
	15.0	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	0.001	99.994

[a] -- Not determined.
[b] Number per field at 400 X magnification.

5 Minute Residuals

When sodium hypochlorite was used as the chlorinating agent, positive tests for total residual chlorine[3] after a 5 minute contact time generally indicated that bactericidal concentrations of chlorine had been reached in secondary effluent (Table 36). Other forms of chlorine and the presence of nitrite in effluent however, gave false positive reactions.

FACTORS AFFECTING CHLORINE ACTIVITY IN LABORATORY TESTS

pH

Portions of a secondary effluent sample were adjusted to pH 5.0 with H_2SO_4; to pH 9.0 with NaOH and left unchanged at pH 7.0. Various amounts of sodium hypochlorite were added and the effects on microorganisms were determined by measuring the inhibition of oxygen uptake and by observing the effect on bacterial motility.

Oxygen Uptake -- D.O. measurements were made hourly for the first four hours of the test then again after 18 hours. An extrapolation of D.O. vs time curves (Figure 29) show that oxygen would have been depleted in the controls within 4.8 to 6.7 hours depending on pH. Uptake was most rapid at pH 9 and slowest at pH 5. Chlorine was inhibitory at all concentrations tested between 4 and 16 ppm (Table 37) but the degree and persistence of activity varied with effluent pH.

At pH 5, 4 ppm Cl increased the time required for oxygen depletion from 6.7 hours to 9.3 hours. Higher concentrations of chlorine prevented depletion for the entire 18 hour period. A characteristic of chlorine at pH 5 was the marked increase in activity as concentrations were increased. Results were similar at pH 7 but here there was not as much difference in activity between 8 and 16 ppm chlorine as there was at pH 5.

Table 36. COMPARISON OF METHODS FOR EVALUATING CHLORINE ACTIVITY. CHLORINE RESIDUAL, BACTERIAL MOTILITY, MEMBRANE FILTER AND MULTIPLE TUBE

Date (1972)	Cl added, ppm	Method of chlorination	5 Min Cl resid	Motile spirilla @ 30 min	Colif/100 ml X 10^5 @ 30 min		Coliform reduction, %	
					M.F.	M.T.	M.F.	M.T.
March 16	0	Laboratory with NaOCl	0	1-10	200	140	--[a]	--
	4.6		0	0.1-1	--	--	--	--
	6.0		0	0.01-0.1	--	--	--	--
	8.0		+	0	0.009	0.014	99.996	99.990
	10.0		+	0	0.038	0.021	99.981	99.985
	10.0	Mill with Cl_2	0	0.1-1	100	80	--	--
	12.5		0	0.1-1	60	90	40.000	0
	12.8		0	0.1-1	90	50	10.000	37.500
	20.5		0	0.01-0.1	30	540	70.000	0
	26.0		+	0.01-0.1	0.037	1.7	99.963	97.875
March 17	0	Laboratory with NaOCl	0	1-10	250	130	--	--
	4.0		0	0.1-1	0.40	0.30	99.840	99.769
	6.0		0	0.01-0.1	0.05	0.02	99.980	99.985
	8.0		+	0	0.30	1.7	99.880	98.692
	10.0		+	0	0.50	0.02	99.800	99.985
	22.2	Mill with Cl_2	0	0.01-1	7.7	17	96.920	86.923
	21.2		0	0.1-1	30	8	88.000	93.846

[a] -- Not determined.

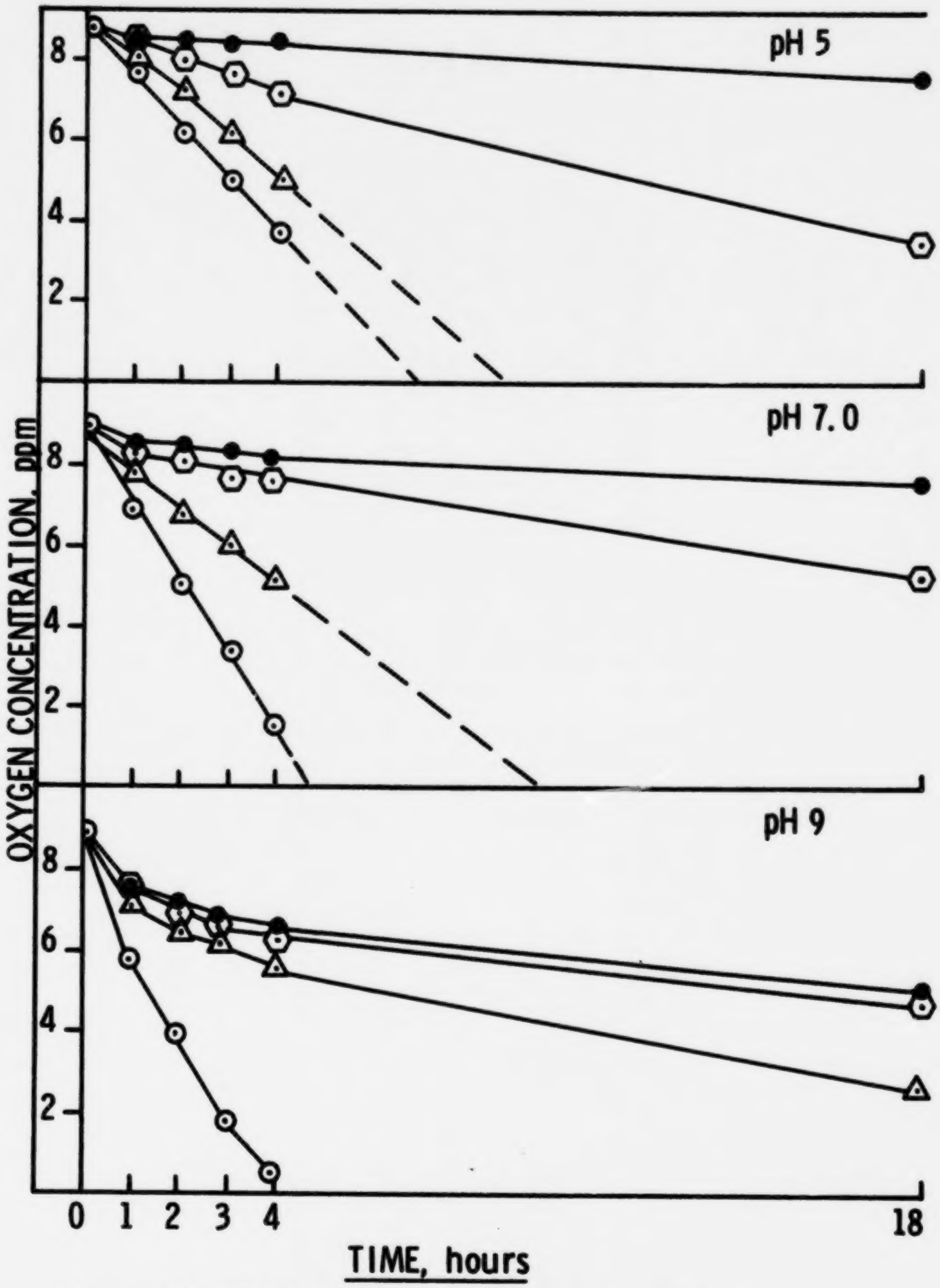

Figure 29. Effect of chlorine on oxygen uptake by secondary effluent at various pHs.
⊙= 0 ppm Cl; △= 4 ppm Cl; ⬡= 8 ppm Cl; ●= 16 ppm Cl

Table 37. EFFECT OF pH AND CHLORINE ON OXYGEN UPTAKE BY SECONDARY EFFLUENT AND ON BACTERIAL MOTILITY

Effluent pH		Cl added ppm	Dissolved oxygen, ppm after:						Inhibition of D.O. uptake, % after:					Motile spirilla/field after:					
Ini	Fin		Ini	1 Hr	2 Hr	3 Hr	4 Hr	18 Hr	1 Hr	2 Hr	3 Hr	4 Hr	18 Hr	5 Min	10 Min	15 Min	30 Min	4 Hr	18 Hr
5.0	5.0	0	8.8	7.6	6.2	5.0	3.7	0.5	0	0	0	0	0	1-10	1-10	1-10	1-10	1-10	1-10
--[a]	5.2	4.0	8.9	8.1	7.2	6.2	5.1	0.3	38	38	29	25	0	1-10	1-10	0.01-0.1	0.01-0.1	0.01-0.1	0.01-0.1
--	5.3	8.0	8.8	8.6	8.0	7.7	7.2	3.6	84	69	71	69	38	0	0	0.01-0.1	0	0	0.01-0.1
--	5.4	16.0	8.9	8.7	8.5	8.4	8.5	7.6	84	85	87	92	84	0	0	0	0	0	0
7.0	6.5	0	8.9	6.9	5.1	3.4	1.5	0.4	0	0	0	0	0	1-10	1-10	1-10	1-10	1-10	1-10
--	6.6	4.0	8.7	7.8	6.8	6.0	5.1	0.4	55	50	51	51	2	1-10	1-10	1-10	1-10	1-10	1-10
--	6.8	8.0	8.9	8.2	8.1	7.7	7.6	5.3	65	79	78	82	58	1-10	0.01-0.1	0.01-0.1	0.01-0.1	0	0.01-0.1
--	6.8	16.0	9.0	8.5	8.5	8.3	8.3	7.6	75	87	87	90	84	0	0	0	0	0	0.01-0.1
9.0	9.0	0	8.9	5.9	4.0	1.8	0.5	0.3	0	0	0	0	0	1-10	1-10	1-10	1-10	1-10	0.01-0.1
--	9.0	4.0	8.7	7.2	6.6	6.2	5.6	2.7	50	57	65	63	30	1-10	1-10	1-10	1-10	0.01-0.1	0
--	8.9	8.0	8.6	7.5	7.0	6.6	6.4	4.8	63	67	72	74	56	1-10	1-10	1-10	0.1-0.1	0	0
--	8.9	16.0	8.5	7.6	7.2	6.7	6.5	5.0	70	74	75	76	59	1-10	0.01-0.1	0.01-0.1	0	0	0

[a] -- Not determined.

The behavior of chlorine at pH 9 differed in three respects from that at the lower pHs.

1. Oxygen depletion was prevented for 18 hours by 4 ppm chlorine, a concentration which was ineffective at lower pHs.

2. Differences in the amounts of chlorine added to effluent had less effect on the rate of oxygen uptake than was found at lower pHs. At pH 9, oxygen uptake curves in the presence of 8 ppm and 16 ppm of added chlorine were almost superimposable.

3. The highest concentration of chlorine tested, 16 ppm, was less effective at pH 9 than at the lower pHs.

The data are presented differently in Figure 30 to show how the effect of pH on chlorine activity differs according to chlorine concentration. Considering first 4 ppm, there was inhibition at pH 5-9 but not enough to consistently meet the critereon of 64 percent inhibition of oxygen uptake (Table 37). At the lower pHs chlorine activity did not persist but at pH 9 it was still apparent after 18 hours. Concentrations of 8 and 16 ppm chlorine, at pH 5, 7 and 9, inhibited oxygen uptake by 64 percent or more, meeting the critereon for effective chlorination. At these higher addition rates activity persisted for at least 18 hours at all pHs.

The results show that low pH effluent favors rapid chlorine activity and limited stability. The reverse occurs at high pH. The intensity or level of chlorine activity is not great in high pH effluent but it remains for a considerable time.

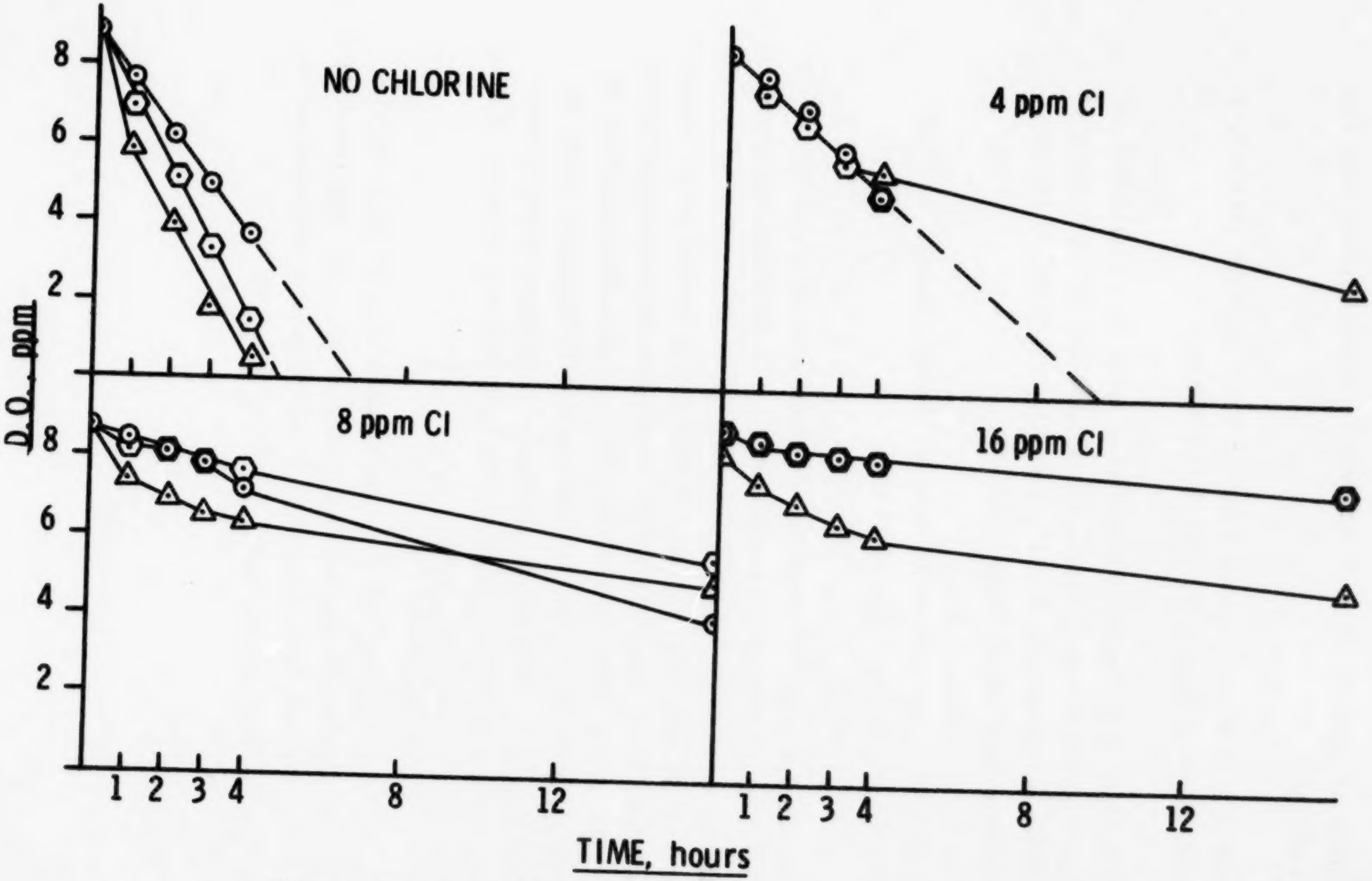

Figure 30. Effect of pH on inhibition of O_2 uptake by chlorine.
⊙= pH 5; ⬡= pH 7; △= pH 9.

The optimum combination of pH and chlorine concentration would provide enough time and activity to kill coliforms in effluent and enough chemical reactivity to be consumed before the treated effluent reaches receiving waters.

Motility -- Results from motility tests also showed that pH had a significant effect on the rate of chlorine activity (Table 37). For example, 8 ppm chlorine stopped bacterial motility within 5 minutes when the effluent pH was 5.0. As the pH was increased more time was required. At pH 7 more than 30 minutes were necessary and at pH 9 motility was stopped only after a reaction time of more than 4 hours. Only at pH 9 was 4 ppm chlorine effective but it required from 4 to 18 hours.

Conclusions based on these results are the same as those from oxygen uptake tests. Low effluent pH favors rapid activity and limited stability; high pH favors the reverse.

Chlorine Residuals -- In these tests, chlorine addition rates were related to activity at various pHs. No analyses were made to determine the actual concentrations of chlorine in the effluent.

In another experiment, sodium hypochlorite was added to secondary effluent samples, adjusted to pH 1.7 to 9.0, to provide initial chlorine concentrations of 10 ppm. Analyses showed that samples with pHs in the range of 5 to 9 contained 2.6 ppm total residual chlorine after 30 seconds (Table 38). After 1 hour, residuals were 1.3 ppm at pH 9 and 0.4 ppm at pH 7. No residuals could be found at pH 5 or below. On the basis of these results and those from the previous tests, the following conclusions can be drawn:

Table 38. EFFECT OF pH ON TOTAL CHLORINE RESIDUALS IN SECONDARY EFFLUENT. APPLICATION RATE 10 PPM.

Eff.	Total resid. Cl, ppm after:						% of Added Cl remaining after:					
pH	30 sec	1 min	2 min	5 min	30 min	1 hr	30 sec	1 min	2 min	5 min	30 min	1 hr
1.70	0	0	0	0	0	0	0	0	0	0	0	0
2.90	0.90	0.90	0.90	0.40	0.40	0	9.0	9.0	9.0	4.0	4.0	0
5.00	2.60	--[a]	1.70	1.70	0.40	0	26	--	17	17	4.0	0
6.95	2.60	--	2.20	1.30	0.40	0.40	26	--	22	13	4.0	4.0
9.00	2.60	2.60	2.60	2.20	1.30	1.30	26	26	26	22	13	13

[a] -- Not determined.

a. Chlorine reacts rapidly with constituents of secondary effluent.

b. The percent of added chlorine remaining increases as effluent pH is increased.

c. At equal or lower concentrations, chlorine is more bactericidal at pH 5 and 7 than at pH 9.

In the preceeding experiment it was found that no chlorine residual could be detected when 10 ppm chlorine were added to effluent which had been adjusted to pH 1.7 (Table 38). The low pH was tested to simulate the reaction near the chlorine-effluent interface during mill chlorination. Here gaseous chlorine is used and its hydrolysis produces low pH solutions by the following reaction:

$$Cl_2 + H_2O \rightarrow HCl + HOCl$$

The pH of mill chlorinating solutions and of mixtures with effluent, near the point of contact, would be in the range of 1-2. Further testing showed that over 19 ppm chlorine were required to produce a 5 minute chlorine residual in pH 1.7 effluent (Table 39).

Table 39. CHLORINE REQUIRED TO PRODUCE 5 MINUTE RESIDUALS[a] IN EFFLUENT AT pH 1.7 AND 7.0

Cl added ppm	5 Minute chlorine residual[a]			
	ppm		% of Added Cl	
	pH 1.7	pH 7.0	pH 1.7	pH 7.0
3.8	0	1.3	0	34
5.8	0	1.8	0	31
9.6	0	2.2	0	23
11.5	0	3.5	0	30
14.4	0	4.9	0	34
19.3	0.9	--[b]	5	--
24.0	1.8	--	7	--
28.8	3.1	--	11	--
34.6	2.2	--	6	--

[a] See Apparatus and Methods.

[b] -- Not determined.

With pH 7 effluent, 3.8 ppm or less were needed. At the relatively high chlorination rate of 50 ppm, 87 percent reacted with effluent within 30 seconds at pH 1.6 but only 38 percent reacted at pH 7 (Table 40). Under the test conditions, volatilization of chlorine from a dilute control solution of H_2SO_4 at pH 1.6 was only 2.6 percent.

Table 40. EFFECT OF pH ON CHLORINE UPTAKE BY SECONDARY EFFLUENT. APPLICATION RATE 50 ppm.

Sample	pH after chlor.	Cl resid. after 30 sec. ppm	Corrected chlorine uptake ppm	Corrected chlorine uptake % of Added
Effluent 1a	1.6	7.1	41.6	85.4
1b	1.6	5.3	43.4	89.1
Ave.	1.6	6.2	42.5	87.3
Effluent 2a	3.0	31.9	17.7	35.7
2b	3.0	32.3	17.3	34.9
Ave.	3.0	32.1	17.5	35.3
Effluent 3a	7.2	31.0	18.6	37.5
3b	7.2	30.6	19.0	38.3
Ave.	7.2	30.8	18.8	37.9
Effluent 4a	8.4	30.1	19.5	39.3
4b	8.4	28.4	21.2	42.7
Ave.	8.4	29.2	20.4	41.1
Dilute H_2SO_4	1.6	48.7	1.3	2.6
Dilute NaOH	8.7	49.6	0.4	0.8

These experiments have shown that reactions between chlorine and secondary effluent are very rapid and complete at pH 1-2. However, the tests were made by adding high pH chlorinating solutions to low pH effluent. In practice, when chlorine gas is used, low pH chlorinating solutions are added to neutral effluent. Evaluation of pH effects on chlorine reactivity was extended to include this condition as well as other combinations of effluent pH and chlorinating solution pH. Results are shown in Table 41 and Figure 31.

Considering first the addition of chlorine to effluent with a normal pH of 7.2, it was found that as the pH of the chlorinating solution was increased, less chlorine was required to provide a 5 minute residual and higher percentages of added chlorine were recovered (Table 41). For example, when the pH of the chlorinating solution was 2.8, a chlorine application rate of 9.8 ppm was required to produce a 5 minute residual and recovery was only 4.4 percent. In contrast, a chlorinating solution with a pH of 10.6 produced a 5 minute residual at an application rate of only 4 ppm chlorine. Recovery averaged 30 percent when the applied rate was in the range of 4 to 10 ppm. Chlorine solutions closer to neutrality gave intermediate results.

The pH of chlorinating solutions influences the following types of reactions which in turn affect the chlorination process:

1. Equilibrium reactions involving chlorine. As shown in Figure 32 the species of chlorine in solution is determined by pH. For example, at pHs between 1 and 2 there are high concentrations of molecular chlorine (Cl_2); at pH 5 chlorine is present as hypochlorous acid (HOCl) only; above pH 5 ionization of HOCl begins and at pH 9 most of the chlorine is in the form of hypochlorite ions (OCl^-).

2. Ionization. The pH of mixtures of chlorine and effluent, near the point of contact, will be influenced by the pH of the chlorinating solution. This in turn may affect the ionization of compounds in the effluent. For example at low pHs the ionization of lignosulfonic acids would be repressed and that of ammonia would be enhanced. With high pH chlorinating solutions the reverse would occur.

Table 41. EFFECT OF CHLORINATING SOLUTION pH AND EFFLUENT pH ON CHLORINE RESIDUALS IN SECONDARY EFFLUENT

pH			Cl added ppm	5 Min. chlorine resid., ppm	Cl recovered, % of added Cl
Cl, soln.	Eff.	Mixt.			
2.8	7.2	7.2	2.0	0	0
		7.0	3.9	0	0
		6.8	5.8	0	0
		6.7	7.8	0	0
		6.5	9.8	0.43	4.4
4.4	7.2	7.3	1.9	0	0
		7.3	3.9	0	0
		7.3	5.8	1.2	21
		7.2	7.7	1.3	17
		7.2	9.6	2.2	23
6.8	7.2	7.6	2.0	0	0
		7.6	3.9	0.43	11
		7.4	5.9	0.86	15
		7.4	7.8	1.72	22
		7.4	9.8	1.72	18
10.6	7.2	7.2	2.0	0	0
		7.5	4.0	0.86	22
		7.4	5.9	1.72	29
		7.4	7.9	2.84	36
		7.4	9.9	3.18	32
12.0	11.0	11.2	1.9	2.84	100
		11.3	3.9	3.44	88
		11.3	5.8	5.15	89
		11.3	7.8	6.00	77
		11.3	9.7	8.60	89
2.0	10.2	9.8	5.3	1.72	32
		9.8	7.1	1.72	24
		9.7	8.9	1.72	19
		9.6	10.7	1.72	16
		9.5	12.4	1.72	14

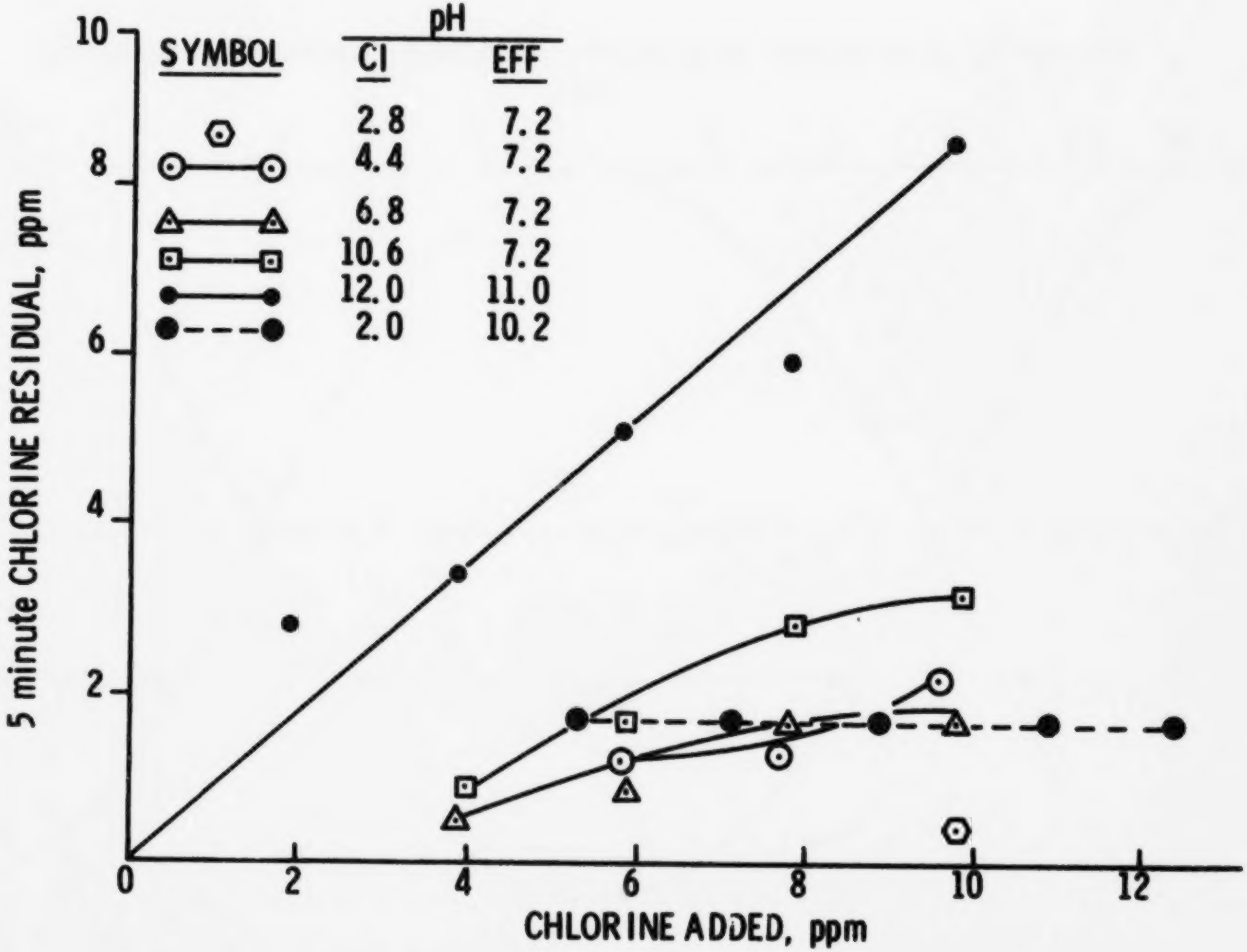

Figure 31. Relationships between applied chlorine and 5 minute residuals in secondary effluent. Effect of pH.

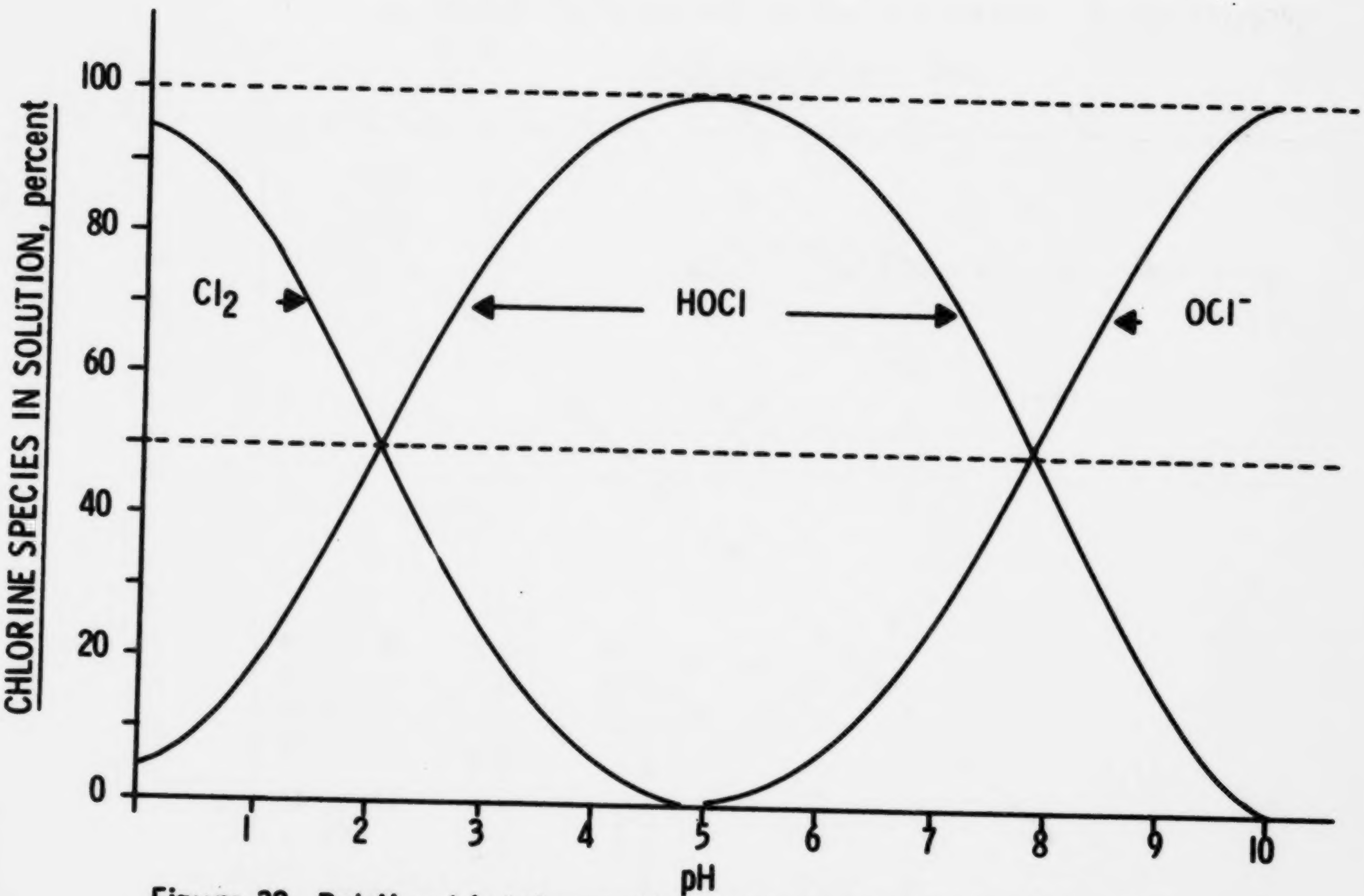

Figure 32. Relationship between pH and chlorine species in 0.1 N solutions.[8]

3. Monochloramine formation. The rate of monochloramine (NH_2Cl) formation is highly dependent upon pH.[9] In dilute solutions, at pH 2, reactions require 421 seconds for 99 percent completion. At pH 8.3 the reaction time again is only 0.07 seconds. At higher pHs the reaction rate is again slower. Lebanon secondary effluent contains over 100 ppm ammonia nitrogen and NH_2Cl has been detected in effluent treated with 12 ppm chlorine added as NaOCl (See Section XII).

The effectiveness of a chlorination process may well depend upon the rates at which the three reactions occur.

When the pH within the reaction zone is about 2, molecular chlorine reacts rapidly with lignosulfonic acids and may be completely inactivated before complete mixing can occur.

At pH 7, HOCl and OCl^- will react more slowly with lignosulfonate ions and there is a possibility for NH_2Cl formation. Monochloramine has bactericidal activity and may react with lignosulfonates at a relatively slow rate. In this situation complete mixing would be expected before the inactivation of chlorine.

If the pH in the immediate reaction zone is about 10 the rate of reaction between OCl^- and lignosulfonates will be very slow leading to complete mixing before significant inactivation of chlorine. Formation of NH_2Cl may take place at some stage prior to complete mixing where the pH of the mixture is between that of the chlorinating solution and effluent and optimum for NH_2Cl formation.

In the extreme condition, where a high pH chlorinating solution (pH 12) was added to a high pH effluent (pH 11), a 5 minute residual was produced with 2 ppm added chlorine and recovery was approximately 90 percent. In this situation chlorine exists as OCl^- and reactions with ionized lignosulfonates and with NH_3 to form NH_2Cl will be slow.

Complete mixing can occur before much chlorine reacts. In the mixture, reactions will continue slowly not only because chlorine will still be present mostly as OCl^- but its concentration will be low because of dilution.

Chlorine Concentration

Reaction rates between chlorine and secondary effluent were measured at pH 1.7 and 7.0. Chlorine was added in the form of sodium hypochlorite. Two chlorine concentrations were tested at each pH, the minimum required to provide a 5 minute residual and twice that concentration. At pH 7.0 the minimum chlorine level was 5.8 ppm compared to 24.0 ppm at pH 1.7. At these concentrations, reaction rates during the first 5 seconds were equivalent to 1730 ppm/hr at pH 7 and 15,400 ppm/hr at pH 1.7 (Table 42). Doubling the chlorine addition increased initial reaction rates by 58 percent at pH 7.0 and by 92 percent at pH 1.7. After the first 5 seconds, rates greatly decreased and within 60 seconds were similar regardless of initial chlorine concentration and pH (Figure 33). With minimal chlorine levels, residuals were not detected after 3 hours. With higher levels of application, residuals persisted for more than 3 hours (Figure 34).

Results showed that effluent pH determined the amount of chlorine required to produce a chlorine residual. In practice the pH of the chlorinating solutions would determine the concentration required. Increasing the amount of chlorine added to effluent increased reaction rates but also led to increased levels of residual chlorine which persisted for more than 3 hours. This would not be desirable in full scale operation. Here, an optimum concentration would be that which would significantly reduce coliform populations in effluent and leave no residual after a contact time equivalent to the passage of effluent to receiving waters. In this case, approximately 4 to 6 hours.

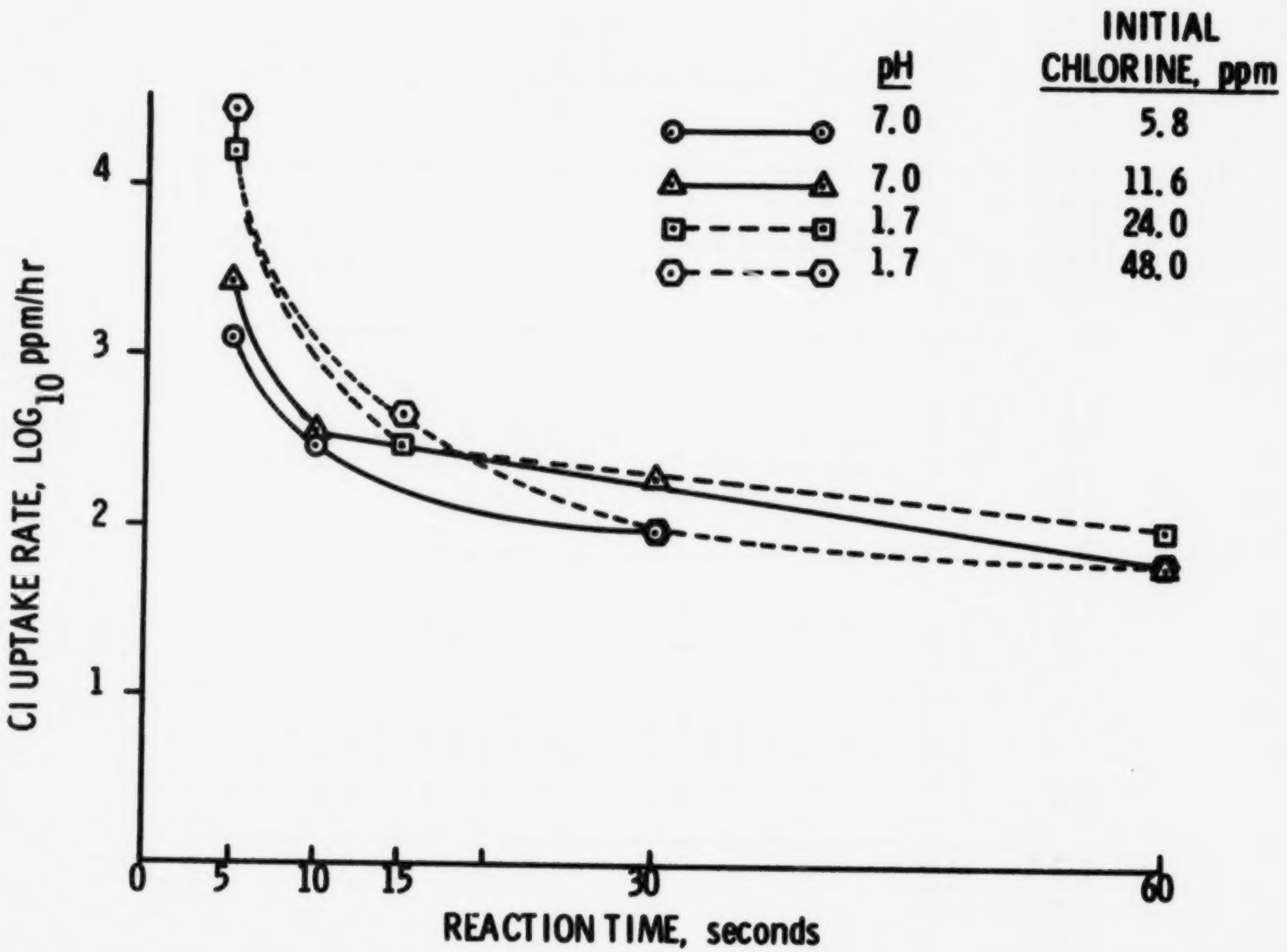

Figure 33. Effect of pH and initial chlorine concentration on reaction rates of chlorine with secondary effluent.

Table 42. EFFECT OF CHLORINE CONCENTRATION ON REACTION RATES

Eff. pH	Cl added, ppm	Elapsed time	Cl resid., ppm	Cl uptake during react. int. ppm	Duration of react. interval	Cl uptake, ppm/hr
7.0	5.8	5 Secs	3.4	2.4	5 Secs	1730
		10 Secs	3.0	0.4	5 Secs	288
		15 Secs	3.0	0	5 Secs	0
		30 Secs	2.6	0.4	15 Secs	96
		60 Secs	2.6	0	30 Secs	0
		2 Mins	2.2	0.4	1 Min	24
		5 Mins	1.7	0.5	3 Min	10
		30 Mins	0.43	1.3	25 Mins	3
		60 Mins	0.43	0	30 Mins	0
		2 Hrs	0.43	0	1 Hr	0
		3 Hrs	0	0.43	1 Hr	0.43
		4 Hrs	0	0	1 Hr	0
	11.6	5 Secs	7.8	3.8	5 Secs	2740
		10 Secs	7.3	0.50	5 Secs	360
		15 Secs	7.3	0	5 Secs	0
		30 Secs	6.5	0.80	15 Secs	190
		60 Secs	6.0	0.50	30 Secs	60
		2 Mins	5.6	0.40	1 Min	24
		5 Mins	5.2	0.40	3 Mins	8
		30 Mins	3.0	2.2	25 Mins	5
		60 Mins	2.2	0.80	30 Mins	2
		2 Hrs	1.7	0.50	1 Hr	0.5
		3 Hrs	0.86	0.84	1 Hr	0.8
		4 Hrs	0	0.86	1 Hr	0.9

Table 42 (continued). EFFECT OF CHLORINE CONCENTRATION ON REACTION RATES

Eff. pH	Cl added, ppm	Elapsed time	Cl resid., ppm	Cl uptake during react. int. ppm	Duration of react. interval	Cl uptake, ppm/hr
1.7	24	5 Secs	2.6	21.4	5 Secs	15,400
		10 Secs	2.6	0	5 Secs	0
		15 Secs	2.2	0.40	5 Secs	288
		30 Secs	2.2	0	15 Secs	0
		60 Secs	1.3	0.90	30 Secs	108
		2 Mins	1.3	0	1 Min	0
		5 Mins	0.86	0.44	3 Mins	9
		30 Mins	0.43	0.43	25 Mins	1
		60 Mins	0	0.43	30 Mins	0.9
		2 Hrs	0	0	1 Hr	0
		3 Hrs	0	0	1 Hr	0
		4 Hrs	0	0	1 Hr	0
	48	5 Secs	6.9	41.1	5 Secs	29,600
		10 Secs	6.5	0.40	5 Secs	288
		15 Secs	5.6	0.90	5 Secs	650
		30 Secs	5.2	0.40	15 Secs	96
		60 Secs	4.7	0.50	30 Secs	60
		2 Mins	4.3	0.40	1 Min	24
		5 Mins	--[a]	--	--	--
		30 Mins	2.6	1.7	28 Mins	4
		60 Mins	2.2	0.40	30 Mins	0.8
		2 Hrs	0.86	1.3	1 Hr	1
		3 Hrs	0.86	0	1 Hr	0
		4 Hrs	0.43	0.43	1 Hr	0.4

[a] -- Not determined.

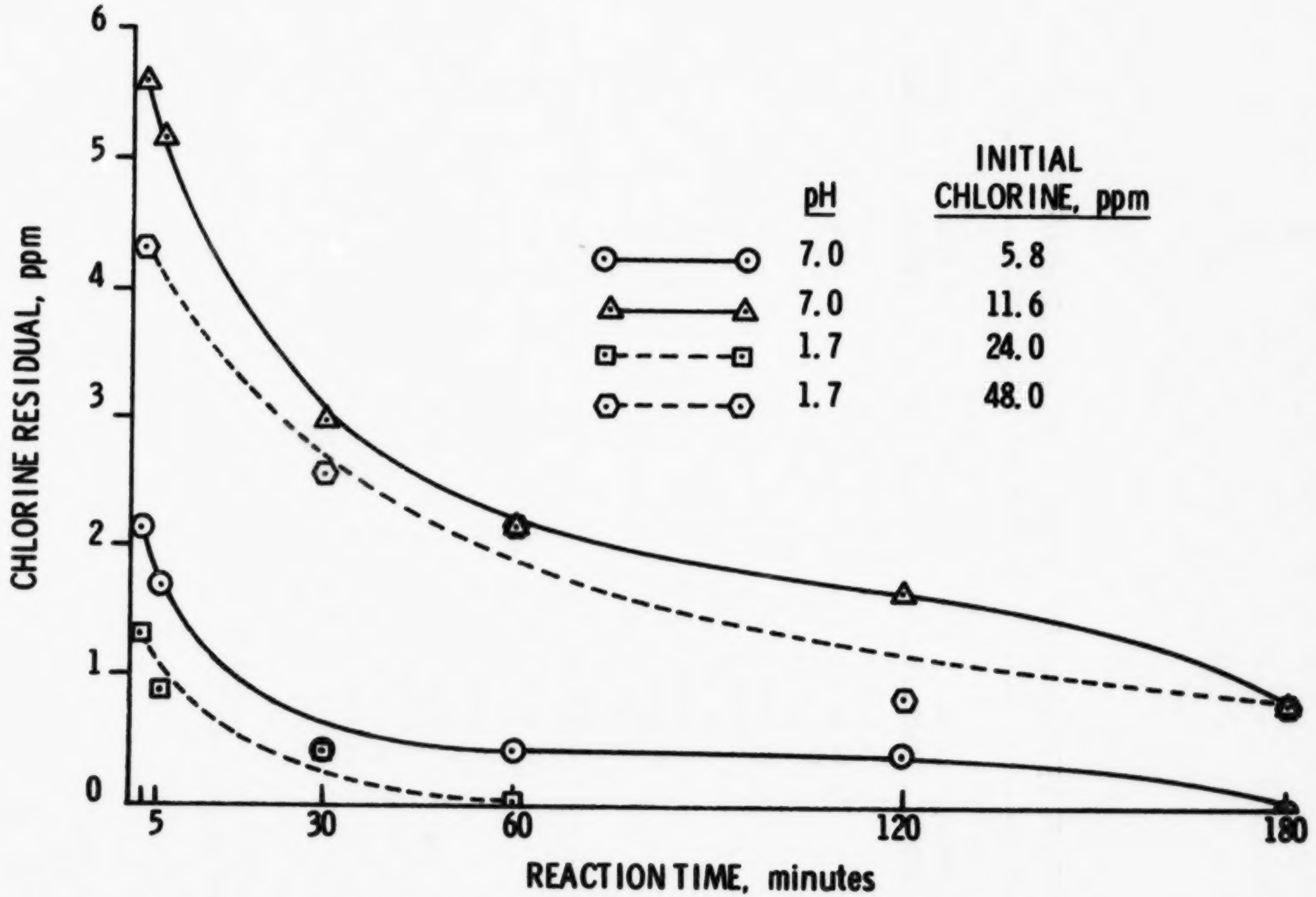

Figure 34. Effect of pH on disappearance of chlorine residuals in secondary effluent.

Dissolved Oxygen

Several conditions could lead to low D.O. concentrations or depletion of oxygen in wastes within the secondary ponds. These include aerator failure, accumulation of sludge beds and overloading. In these situations, bacteria could produce compounds which have a rapid demand for chlorine, e.g., $SO_3^{=}$, S^{-} and aldehydes, thereby increasing the Bacteriological Chlorine Demand. The effect of anaerobic growth conditions on chlorine demand was investigated in a laboratory experiment. Under the most drastic conditions, 3 days of anaerobic incubation, bacterial motility was not completely stopped by 10.4 ppm of added chlorine. In contrast, only 5.2 to 6.2 ppm were required for the mildest treatment (Table 43). This was a sample which had been refrigerated overnight then aerated before testing. The results showed that anaerobic conditions in secondary wastes can lead to increased chlorine requirements.

Sulfite

During secondary treatment there is a reduction in the concentration of compounds which react with chlorine. An example is shown in Table 44. In this test, waste samples were diluted 1:10 in order to obtain excess chlorine with application rates similar to those used in practice. Chlorine uptake for diluted influent samples was 19 and 26 ppm compared to 7 and 9 ppm for diluted effluent. Sulfite accounted for 90 and 48 percent of the total chlorine uptake in the two influent samples. According to the following equation 0.89 ppm chlorine reacts with 1 ppm sulfite:

$$Cl_2 + SO_3^{=} + H_2O \longrightarrow SO_4^{=} + 2Cl^{-} + 2H^{+}$$

This reaction is very important with respect to chlorine requirements of secondary influent. Under normal conditions sulfite concentrations are reduced to low levels during secondary treatment and reactions

Table 43. EFFECT OF ANAEROBIC INCUBATION ON CHLORINE ACTIVITY

Sample #	Pre-chlorination treatment	Cl added, ppm	Motile spirilla/field @ 30 mins	Effective Cl conc., ppm
1	Refrigerated overnight then tested at 20° C.	0	1-10	6.2-8.3
		5.2	0.1-1	
		6.2	1-10	
		8.3	0	
		10.4	0	
2	Same as 1 but aerated before chlorinating	5.2	0.1-1	5.2-6.2
		6.2	0	
		8.3	0	
		10.4	0	
3	Incubated anaerobically for 16 hrs. at 20° C.	5.2	1-10	6.2-8.3
		6.2	1-10	
		8.3	0	
		10.4	0	
4	Same as 3 but aerated to a D.O. conc. of 9.1 ppm	5.2	0.1-1	6.2-8.3
		6.2	0.01-0.1	
		8.3	0	
		10.4	0	
5	Incubated anaerobically for 3 days at 20° C.	5.2	1-10	> 10.4
		6.2	1-10	
		8.3	0.1-1	
		10.4	0.01-0.1	

Table 44. CHLORINE UPTAKE BY SECONDARY WASTES AND BY SULFITE

Date (1972)	Sample	Sulfite in sample, ppm	Cl added, ppm	5 Min Cl resid., ppm	Chlorine uptake		
					ppm	% of added	% of total due to $SO_3^=$
March 14	Effluent (1:10)	0.25	50.0	41.0	9.0	18	2.4
March 14	Influent (1:10)	19.0	50.0	31.0	19.0	38	90
March 15	Influent (1:10)	14.0	48.0	22.0	26.0	54	48
March 16	Effluent (1:10)	0.22	50.0	43.0	7.0	14	2.9
April 10	$NaHSO_3$ in water	10.5	92.0	82.0	10.0	11	93

with chlorine become less important. Less than 3 percent of the total chlorine uptake by diluted effluent could be attributed to sulfite. In actual practice however sulfite in undiluted effluent may have a greater effect on chlorine requirements. The mean sulfite concentration of 22 secondary effluent samples was 3.6 ppm with a range of 2.8 ppm to 4.9 ppm (Table I, Appendix). In terms of chlorine demand the mean would be 3.2 ppm with a range of 2.5 ppm to 4.4 ppm. The mean chlorine demand value is approximately half of the total chlorine requirement of secondary effluent. It is important to recognize that the sulfite values shown may be too high. The iodate titration procedure used is not specific and it does give high values in the presence of organic matter.[3]

In view of the practical importance of sulfite with respect to chlorine requirements, additional studies were made to determine the nature and rate of its oxidation. A mixture containing 50 percent secondary influent and 50 percent secondary effluent (v/v) was used in the tests. To evaluate the role of microorganisms half of the mixture was heated for 2 hours at 80° C to kill a substantial portion of the microbial population, then cooled to room temperature. To measure oxygen uptake rates, a portion of this mixture and the unheated control were mechanically aerated and transferred to BOD bottles. D.O. concentrations were measured at intervals. For the determination of sulfite oxidation rates, the mixtures were transferred to 2 L graduated cylinders and aerated mechanically at the start of the test and at intervals of one hour or less. Periodically, aliquots were titrated with standard iodate to determine sulfite concentrations.[3] D.O. levels were close to saturation throughout this test.

For both samples D.O. utilization was linear with time until D.O. concentrations became limiting (Figure 35). The unheated control consumed oxygen at a rate of 1.9 ppm/hr compared to only 0.2 ppm/hr for the heated sample. Thie represents an 89 percent reduction due to

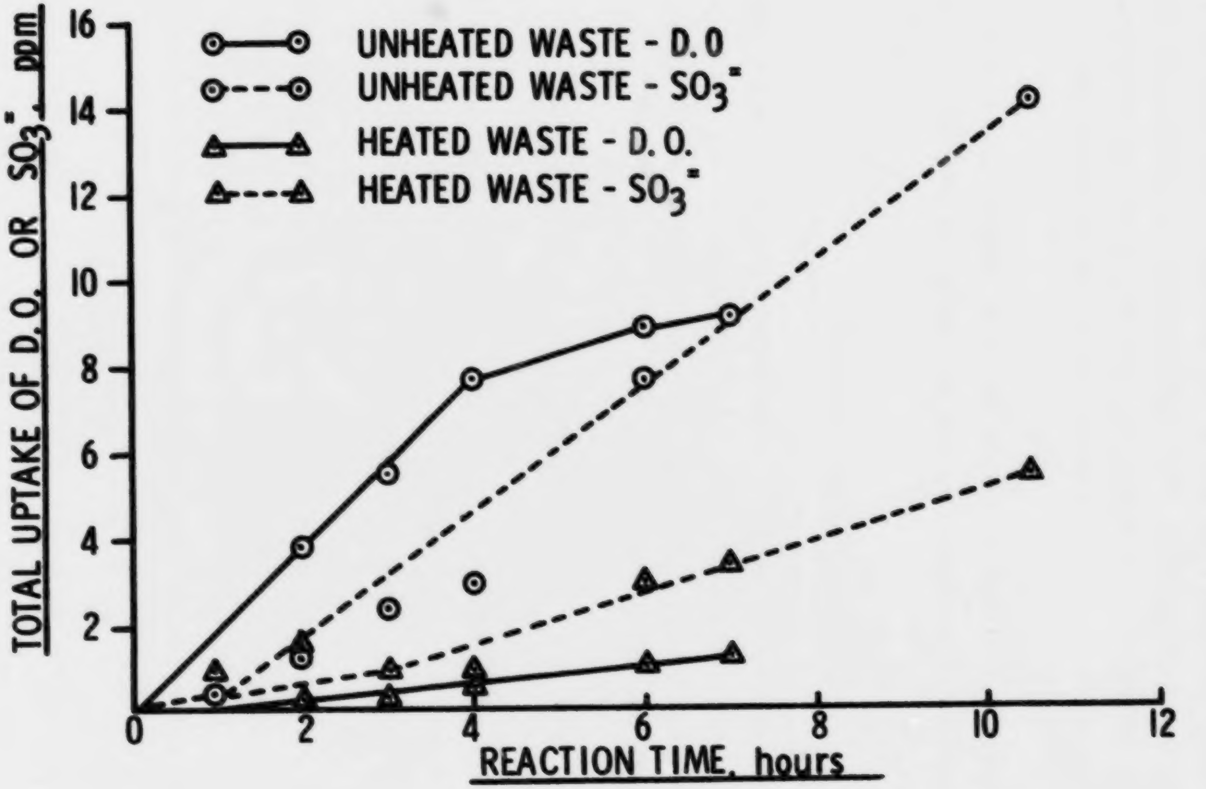

Figure 35. D.O. uptake and sulfite oxidation by mixtures of secondary wastes.

heating. The curves relating sulfite oxidation and time show that the unheated control oxidized 1.35 ppm of SO_3 per hour. The rate for the heated sample was 0.51 ppm/hr. The reduction due to heating was 62.2 percent which indicates that biological activity plays an important role in the oxidation of sulfite in secondary wastes (Table 23).

The contribution of sulfite oxidation to total oxygen uptake in the wastes was calculated according to the following considerations. In the reaction:

$$SO_3^{=} + \tfrac{1}{2}O_2 \longrightarrow SO_4^{=}$$

1 ppm D.O. reacts with 5 ppm $SO_3^{=}$. The amount of D.O. required for an oxidation can be obtained by dividing the amount of $SO_3^{=}$ oxidized by 5. The percent of total D.O. uptake due to sulfite oxidation was calculated with the following equation:

$$\begin{array}{l} SO_3^{=} \text{ Oxid, \%} \\ \text{of Total Oxidation} \end{array} = \frac{SO_3^{=}\text{, ppm/hr x 0.2}}{\text{D.O., ppm/hr}} \times 100$$

Sulfite oxidation was determined by chemical analysis for sulfite, at intervals. Total D.O. utilization was measured with an oxygen probe under conditions where oxygen was not rate limiting.

It was found that sulfite oxidation could account for only 14 percent of the total D.O. uptake in the control and for 51 percent in the heated sample. In the latter case much of this oxidation was probably chemical. As indicated earlier, however, on a rate basis sulfite was utilized more rapidly in the unheated sample.

The finding that $SO_3^{=}$ oxidation takes place slowly in secondary wastes and that it is due mainly to microbial activity has practical implications. For example, the mean sulfite concentration for influent samples taken over a five month period was 142 ppm (Table II, Appendix). At an oxidation rate of 1.35 ppm/hr, as was measured for the unheated control, it would take 4.3 days for complete oxidation of the sulfite. This is close to the retention time of the aerated stabilization basins when operated in parallel. Any condition which would decrease the rate of sulfite oxidation or increase the amount of sulfite added to the basins could result in higher concentrations of sulfite in secondary effluent and, consequently, higher chlorine requirements for coliform control. Using the results obtained with the heated waste, as an extreme example, it can be calculated that 11.6 days would be required for complete sulfite oxidation or that after the normal retention time of 4.8 days there would still be approximately 88 ppm sulfite remaining with a rapid chlorine demand of 71 ppm.

Sulfite is largely responsible for the high chlorine requirement of secondary influent. However it is not the only chlorine demanding compound present. For example, the influent sample taken on March 15 had a larger chlorine requirement than the sample taken on March 14 (Table 44) even though the former contained less sulfite.

Carbohydrates

If the BOD load to secondary treatment ponds is increased, it is probable that the concentration of sugars in secondary effluent also will increase. The relevance of this to mill chlorination was evaluated using glucose as a representative reducing sugar. At a chlorination rate of approximately 10 ppm, chlorine uptake by a 1000 ppm glucose solution was only about 5 percent of that found for secondary effluent. At higher chlorination rates the value increased to 11 percent (Table 45). Increased sugar concentration in effluent due to overloading would, therefore, not significantly increase chlorine demand.

Table 45. COMPARISON OF CHLORINE UPTAKE BY SECONDARY EFFLUENT AND GLUCOSE

Sample	Cl added, ppm	5 Min Cl resid. ppm	Cl uptake, ppm	Cl uptake by glu., % of uptake by eff.
Sec. effluent	10	0.85	9.2	a
1000 ppm Glucose	8.3	7.8	0.5	5.4
Sec. effluent	50	15	35	a
1000 ppm Glucose	42	38	4	11

[a] No glucose added.

Particulates

During secondary treatment there is a seven fold increase of total bacteria in the waste (Table 10). In effluent samples the mean concentration of total bacteria was 2.8 billion per 100 ml. The large standard deviation (SD) of ± 2.6 billion per 100 ml suggested that wide variations in the concentrations of bacteria and other particles could affect the chlorine requirements of secondary effluent. This possibility was evaluated by determining the relative reactivity, with chlorine, of the soluble and particulate components of effluent. To separate the components, a secondary effluent sample was centrifuged for 5 minutes at a force of 9750 xg. The supernatant was clarified further by filtration through a 0.45 µm porosity membrane filter. Various amounts of chlorine were added to sub-samples of the particle free effluent and to sub-samples of effluent which had not been treated to remove particles. Total residual chlorine was determined after contact times of 5 minutes. The differences in chlorine uptake by the two sets of samples were attributed to particles. When the concentration of added chlorine was in the range of 4 to 10 ppm, the average chlorine uptake by particles was approximately 0.4 ppm and it did not increase with increasing rates of chlorine addition (Table 46).

Table 46. CHLORINE UPTAKE BY PARTICULATE AND SOLUBLE COMPONENTS OF SECONDARY EFFLUENT

Cl added, ppm	5 Min Cl res, ppm		Cl uptake, ppm		Cl uptake due to particles	
	Effluent	Effluent - particles	Effluent	Effluent - particles	ppm	Percent
0	0	0	0	0	0	0
2.0	0	0	0	0	0	0
4.0	1.6	1.9	2.4	2.1	0.3	12
6.0	2.2	2.7	3.8	3.3	0.5	13
8.0	3.0	3.5	5.0	4.5	0.5	10
10	4.0	4.2	6.0	5.8	0.2	3

Chlorine uptake due to particles was only 10 percent of the total chlorine uptake by secondary effluent. These results show that wide variations in concentrations of bacteria and other particles will have little effect on the amounts of chlorine required to obtain residuals in secondary effluents.

Lignosulfonates

The maximum chlorine demand of reducing sugars plus particles in secondary effluent is approximately 1 ppm. Sulfite may increase the demand to approximately 4 ppm although this estimate may be too high (see Sulfite). This is considerably less than the chlorine uptake by all of the constituents of secondary effluent. In previous experiments, it was found that chlorine uptake by secondary effluent, within 5 minutes, exceeded 25 ppm and was proportional to added chlorine up to at least 40 ppm (Figure 27). This is 10 times the requirement associated with the materials considered thus far. Other reactants are not present in great excess because when equal amounts of chlorine were added to mixtures of secondary effluent and water, the amounts of chlorine reacted decreased in proportion to the decrease in effluent concentration (Table 47, Figure 36).

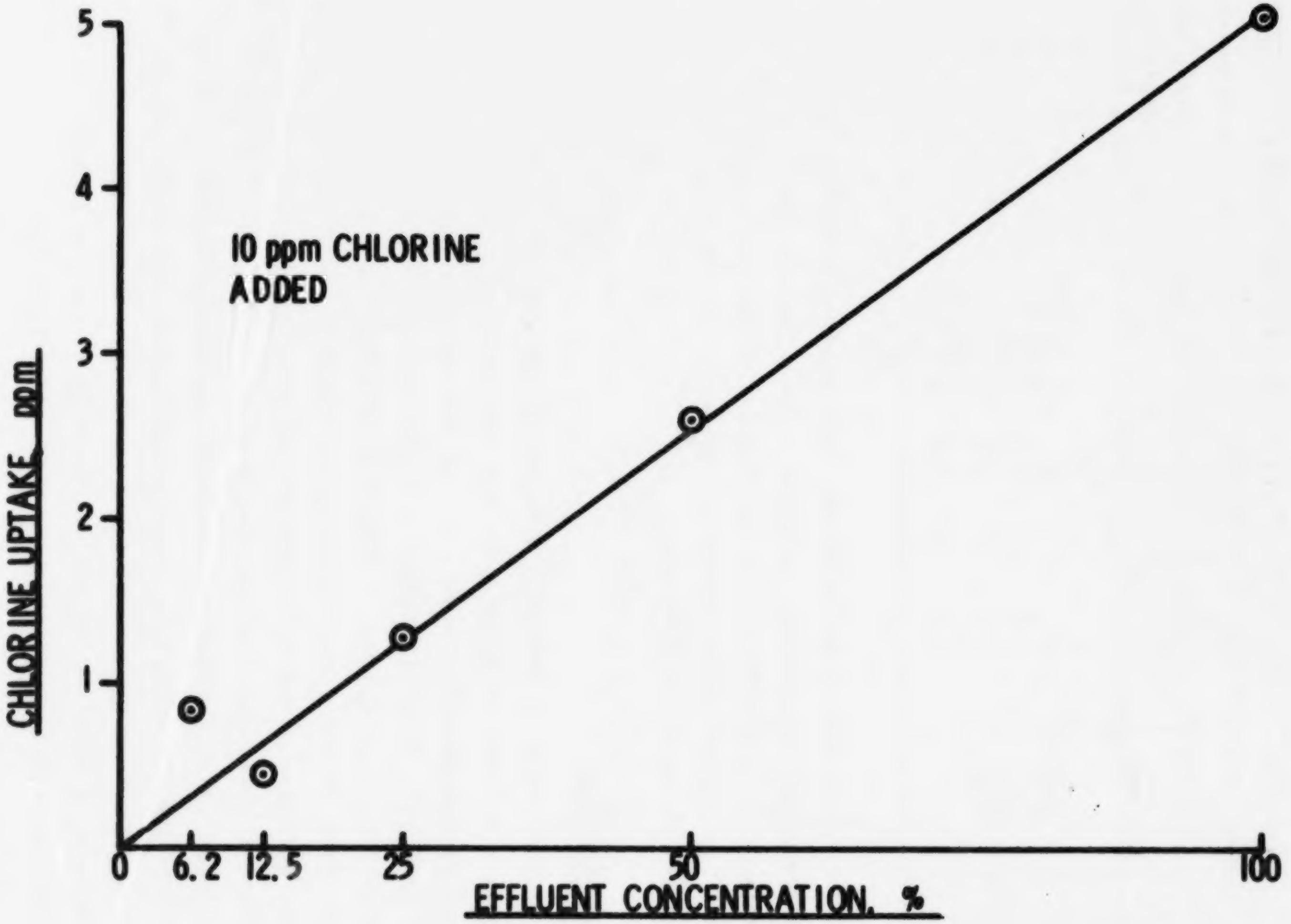

Figure 36. Effect of effluent concentration on chlorine uptake.

Table 47. RELATIONSHIP BETWEEN EFFLUENT CONCENTRATION AND CHLORINE UPTAKE

Sample vol., ml		Cl added, ppm	5 Min Cl resid., ppm	Chlorine uptake	
Eff.	Water			ppm	% of Added
0	100	10	9.9	0	0
6.25	93.75	10	9.05	0.85	8.5
12.5	87.5	10	9.45	0.45	4.5
25.0	75.0	10	8.61	1.29	12.9
50.0	50.0	10	7.30	2.60	26.0
100	0	10	4.82	5.08	50.8

It is likely that lignosulfonates are responsible for most of the chlorine uptake by the secondary effluent for the following reasons:

a. Excluding cellulose, they are the major reaction products of the sulfite process.

b. They are resistant to microbial breakdown.[10]

c. They contain unsaturated aliphatic and aromatic groups which can react with chlorine.[8]

d. The capability of secondary effluent to react with large amounts of chlorine has not been associated with any other materials.

The amount of lignosulfonates going into the secondary ponds may vary in response to changes in the ratio of normal to high yield cooks and/or variations in the amounts of lignosulfonates utilized for by-products. The variations observed in chlorine uptake by secondary influent samples, independent of their sulfite concentrations, (Table 44) may have been due to differences in lignosulfonate concentrations caused by the variations in processing. This also may explain the inconsistent results obtained when secondary effluent was chlorinated using the mill system (Table 34).

SECTION XI

FULL SCALE CHLORINATION

DESCRIPTION OF CHLORINATING SYSTEM

A schematic of the mill chlorination system is presented in Figure 37. The chlorinator, which is not shown, was a Wallace and Tiernan Series V800 Module with a maximum metered chlorine output of 454 Kg/day (1000 #/day). Injector water flow supplies the pressure drop necessary for the operation of the chlorinator and dilutes the chlorine to approximately 3500 ppm. The chlorine solution is discharged into turbulent effluent in #2 sump. This mixes in a Parshal flume with unchlorinated effluent from #1 sump. The combined effluents are then discharged to Mark Slough which provides a retention time of 4 to 6 hours before reaching the South Santiam River.

Effluent flow was continuously recorded in thousands of gallons per hour (TGH). Chlorine flow, which was manually adjusted, was indicated by a rotameter calibrated in pounds per day. The initial concentration of chlorine in effluent was calculated by the following formula:

$$\begin{array}{l}\text{Initial} \\ \text{Cl Conc, ppm}\end{array} = \frac{5 \times \text{\#/Day Cl}}{\text{Total Flow, TGH}}$$

On the basis of results from the laboratory experiments, provisions were made for increasing the pH of the chlorinating solutions. A port was installed in the injector water supply to allow addition of NaOH or other solutions.

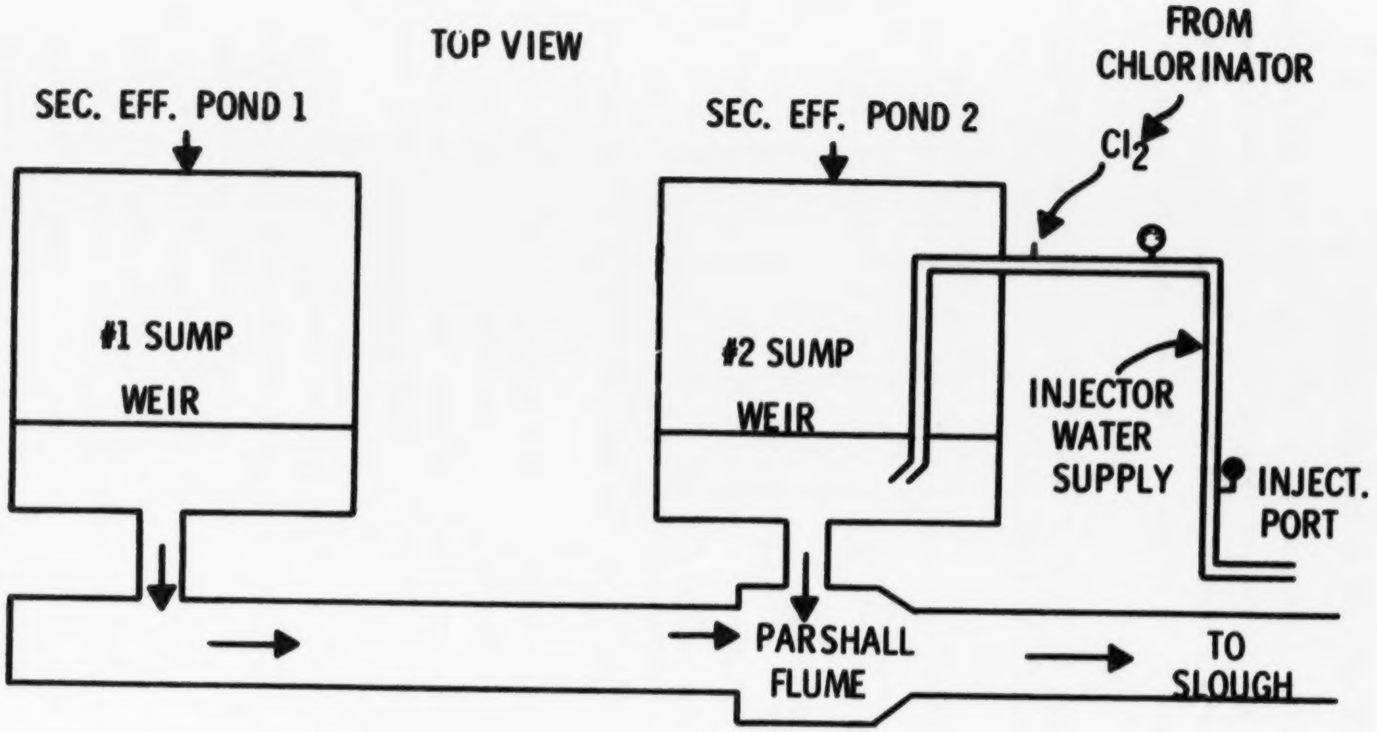
TOP VIEW
SEC. EFF. POND 1
#1 SUMP
WEIR
SEC. EFF. POND 2
#2 SUMP
WEIR
FROM CHLORINATOR
Cl_2
INJECTOR WATER SUPPLY
INJECT. PORT
PARSHALL FLUME
TO SLOUGH

Figure 37. Mill secondary effluent discharge and chlorination systems.

EFFECT OF NaOH ADDITION ON CHLORINE ACTIVITY

A series of tests made during May 1972, showed that the existing chlorination system was not able to supply bactericidal concentrations of chlorine consistently. In 4 out of 5 trials, motility of spirilla was not stopped by 19-23 ppm of added chlorine (Table 48).

Table 48. EFFECT OF MILL CHLORINATION ON BACTERIAL MOTILITY AND COLIFORMS. SUMMARY OF DATA

Measurement	Date (May 1972)				
	17	18	19	25	26
Chlorine required to stop motility, ppm	> 21.2	> 21.2	> 19.2	20.4	> 23.5
Chlorine required for 99.99% coliform reduction, ppm	--[a]	> 21.2	--	20.4	--
Drop in effluent pH due to chlorination	> 0.5	> 0.5	> 0.5	0.6	> 0.6

[a] -- Not determined.

This was equivalent to the maximum metered output of the chlorinator of 454 Kg/Day (1000 #/day). The variations in applied chlorine concentrations were due to differences in effluent flow rates. Complete results for these experiments are given in Table V, Appendix.

In other mill trials it was found that the addition of caustic to the chlorinator's injector water supply dramatically improved chlorine performance. For example, without caustic addition, more than 17 ppm chlorine were required for bactericidal activity and in some cases required concentrations could not be reached. With the addition of caustic, bactericidal concentrations of chlorine were obtained with 4.2 to 7.0 ppm of applied chlorine (Table 49). These results confirm the findings of laboratory experiments on pH effects which were discussed

Table 49. USE OF CAUSTIC IN CHLORINATION SYSTEMS.
SUMMARY OF MILL EVALUATIONS

Date (1972)	Chlorine req. for bactericidal activity, ppm		Total residual chlorine, ppm after:				Effluent pH				
			5 Minutes		2 Hours		Before Chlor.	After chlor.		Change due to chlorination	
	No NaOH	With NaOH	No NaOH	With NaOH	No NaOH	With NaOH		No NaOH	With NaOH	No NaOH	With NaOH
May 25	20.4	4.5	2.7	0.78	0.86	0	6.9	6.3	7.0	-0.6	+0.1
May 26	> 23.5	7.0	2.6	1.7	0.86	0	6.9	6.2	6.8	-0.7	-0.1
June 29	--[a]	4.2	--	1.4	--	0	--	--	--	--	--
July 20	> 9.1	5.6	1.7	2.7	0.69	0	6.4	--	--	--	--
July 21	16.4	5.0	3.2	1.7	1.7	0.52	6.6	5.8	6.6	-0.8	0
Mean	17.4	5.3	2.6	1.7	1.0	0.10	--	--	--	-0.7	0

[a] -- Not determined.

in the preceeding section. Caustic addition had other beneficial effects. By neutralizing HCl and HOCl formed by chlorine hydrolysis, it held effluent pH changes to ± 0.1 unit. Without caustic, chlorination caused changes of 0.6 to 0.8 pH unit. In only 1 out of 5 trials was there any residual chlorine after 2 hours when caustic was used, whereas, conventional chlorination consistently produced 2 hour residuals.

Results from individual trials showed some interesting effects due to the pH of chlorinating solutions. When NaOH was used to increase the pH, excellent correlation was found between chlorine concentrations required to produce a 5 minute residual, to stop bacterial motility and to reduce coliforms to satisfactory levels (Table VI, Appendix). Without caustic addition, 5 minute residuals could be attained which persisted for 2 hours but there was little or no correlation between this and bactericidal activity. Results from the trial of July 21 provide a good example of this.

Without caustic addition, chlorine uptake was proportional to that added over the entire concentration range which provided a 5 minute residual (Figure 38). The curve is similar to that found with sodium hypochlorite in laboratory studies and shows that the increase in reaction rates is due to an increase in the concentration of one of the reactants; namely, chlorine.

Relationships between chlorine uptake and added chlorine were complex when caustic was added to the system. At the lower addition rate of 8 ppm NaOH, chlorine uptake increased only slightly with increasing rates of chlorine addition, up to about 13 ppm of added chlorine. Further increases in concentrations caused a sharp increase in the rate of chlorine uptake. After the break point, the slope of the Chlorine Uptake vs Chlorine Added curve became steeper than the one obtained for the control of chlorination (Figure 38).

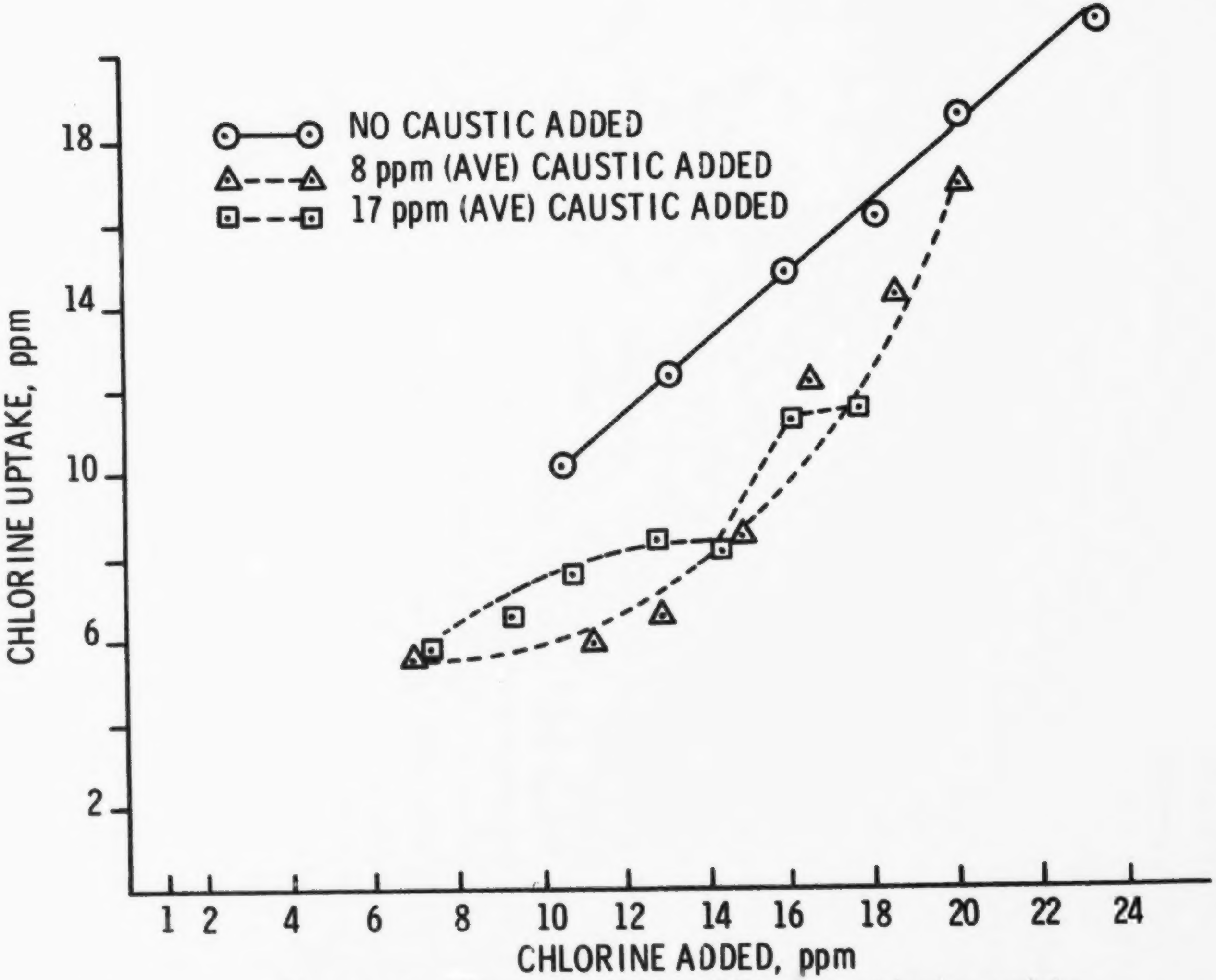

Figure 38. Effect of caustic addition on chlorine uptake by secondary effluent. Mill chlorination.

This coincided with a decrease in the pH of chlorinated effluent (Table VI, Appendix) and indicates a drop in the pH of the chlorinating solution and a shift in equilibria of chlorine species toward the more reactive forms, i.e. hypochlorous acid and molecular chlorine. The greater rate of chlorine uptake in the experimental system, after the breakpoint had been reached, may have been due to higher reaction temperatures near the contact point. The heat could be generated in part by dilution of the concentrated caustic solutions in the injector water and by neutralization reactions between diluted caustic and chlorine.

The importance of maintaining a high pH chlorinating solution is also shown in the relationships between applied chlorine and the 5 minute chlorine residuals. Using conventional chlorination, residuals were obtained with 10.6 ppm of applied chlorine and their concentration gradually increased in a linear manner with increased rates of application (Figure 39). With the modified procedure using caustic, residuals were obtained at lower chlorine addition rates and they increased much faster as more chlorine was added, up to a concentration of 13 ppm. With further increases, the chlorine concentration of residuals decreased. This again demonstrated that neutralization reactions were not complete and that there was a change in the nature of the chlorinating solution, i.e., the conversion of slow reacting sodium hypochlorite to the more reactive forms because of pH changes.

CAUSTIC REQUIREMENTS FOR IMPROVED CHLORINATION

According to the following reactions, 1 mole of molecular chlorine requires 2 moles of NaOH for complete neutralization:

$$\begin{array}{rl} \mathrm{Cl_2 + H_2O} & \rightarrow \mathrm{HCl + HOCl} \\ \mathrm{2\ NaOH + HCl + HOCl} & \rightarrow \mathrm{NaCl + NaOCl + 2\ H_2O} \\ \hline \mathrm{2\ NaOH + Cl_2} & \rightarrow \mathrm{NaCl + NaOCl + H_2O} \end{array}$$

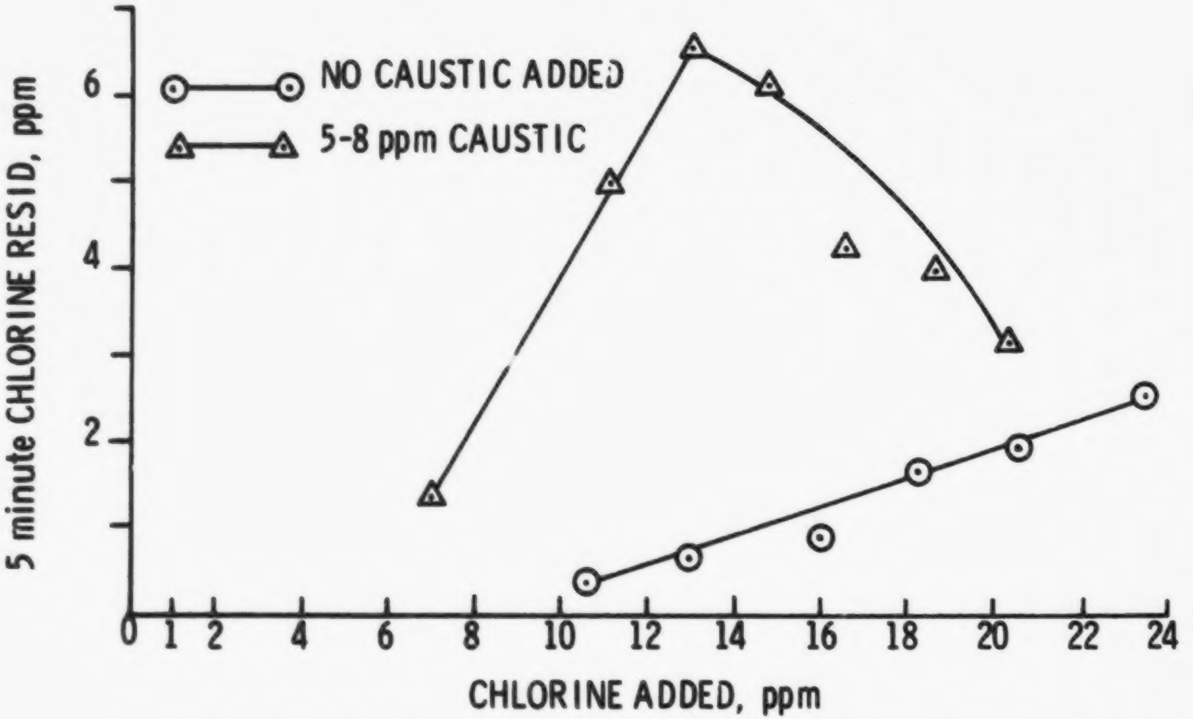

Figure 39. Effect of caustic addition on chlorine residuals obtained from mill chlorination of secondary effluent.

On a weight basis the requirement is 1.128 parts of NaOH (2.256 parts of commercial 50% caustic) per part of chlorine. Calculations based on this were made using data obtained on May 25 and 26 (Table VI, Appendix). The results (Table 50) show that 89 to 96 percent of the chlorine added to effluent reacted within the first 5 minutes, if the chlorinating solution was not neutralized. With the addition of NaOH, chlorine uptake was reduced to 49 to 85 percent depending on the amounts of chlorine and caustic used. The relationships between the degree of neutralization (theoretical) and chlorine uptake appeared to be incongruous. For example, at chlorine application rates up to 272 Kg/day (600 #/day) the low and medium NaOH additions were more beneficial than the high rate of NaOH application. With further increases in chlorine the highest rate of NaOH addition was more effective. To generalize, the lower rates of caustic addition were more effective unless the amount of NaOH added became a limiting factor. Neutralization rates of 40 to 50 percent of the theoretical amounts required for complete neutralization improved chlorination performance. This indicates that neutralization of the HCl formed from chlorine hydrolysis may be adequate and that neutralization of the other acidic hydrolysis product, hypochlorous acid, was not necessary.

The relatively poor performance of high concentrations of caustic was probably due to methods of application. The most satisfactory procedure was used for the lowest application rate. A 25 percent NaOH solution (w/w) was pumped from a 5 gallon bucket into the injector water line by a continuous delivery Jabsco pump. Usage was determined by periodic weighing of the bucket. To obtain higher application rates it was necessary to use a double action piston pump and 50 percent NaOH. This tended to give intermittent rather than continuous delivery and possibly slowed the rate of caustic dilution with injector water. Either condition would produce a chlorinating solution of fluctuating pH and one which would vary in effectiveness. These problems would be expected to increase with higher rates of caustic addition.

Table 50. EFFECT OF NaOH ADDITION RATES ON CHLORINE RESIDUALS

Chlorine added			NaOH added, ppm				Cl neut., % of theo				3 Min Cl resid., ppm				Cl uptake, % of added			
							NaOH add. rate				NaOH add. rate				NaOH add. rate			
Kg/day	(#/day)	ppm	Cent	Low rate	Med rate	High rate	Cent	Low	Med	High	Cent	Low	Med	High	Cent	Low	Med	High
45	(100)	2.2, 2.1	0	6.0	--ª	--	0	253	--	--	0	0	--	--	100	100	--	--
68	(150)	3.2, 3.2	0	6.1	--	--	0	169	--	--	0	0	--	--	100	100	--	--
91	(200)	4.2, 4.5	0	6.5	--	--	0	128	--	--	0	0.78	--	--	100	83	--	--
113	(250)	5.2, 5.7	0	6.5	--	--	0	101	--	--	0	1.4	--	--	100	75	--	--
136	(300)	6.2, 6.8	0	6.5	--	--	0	85	--	--	0.69	1.6	--	--	89	76	--	--
182	(400)	8.2, 9.1	0	6.6	--	--	0	66	--	--	0.69	3.1	--	--	92	66	--	--
227	(500)	10.2, 11.1	0	6.4	--	--	0	51	--	--	1.1	5.9	--	--	89	47	--	--
272	(600)	12.5, 13.0	0	6.2	--	--	0	42	--	--	1.4	6.5	--	--	89	30	--	--
318	(700)	14.5, 15.2	0	6.3	--	--	0	37	--	--	1.4	5.6	--	--	90	63	--	--
91	(200)	3.6-4.8	0	5.2	8.5	18	0	98	160	443	0	0	0	0	100	100	100	100
136	(300)	5.5-7.0	0	5.0	8.4	13	0	63	106	210	0	1.7	1.4	0	100	76	80	100
182	(400)	7.3-9.5	0	4.3	12	18	0	40	116	219	0	2.5	--	1.7	100	74	--	77
227	(500)	9.3-12.1	0	5.6	4.8	16	0	40	38	153	0.43	5.3	5.1	2.6	96	56	54	72
272	(600)	10.8-14.6	0	6.1	7.7	18	0	37	53	148	0.89	5.8	6.6	3.1	95	60	69	71
318	(700)	12.8-16.7	0	6.0	6.1	18	0	32	37	125	0.95	4.5	8.2	4.3	94	73	58	66
363	(800)	14.3-19.0	0	7.7	7.5	18	0	36	40	112	1.7	3.0	4.3	6.0	91	84	74	58
408	(900)	16.1-21.3	0	3.4	10	18	0	14	48	99	2.0	3.1	4.1	4.7	90	85	78	71
454	(1000)	17.7-23.5	0	3.4	5.8	18	0	13	25	90	2.6	--	3.2	6.1	89	--	84	66

ª -- Not tested.

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Time also may have been a factor limiting the effectiveness of high levels of NaOH. The following reactions have to occur within a few feet of pipe containing rapidly flowing liquids:

a. Uniform mixing of caustic and injector water.

b. Complete solution and ionization of NaOH before contact with chlorine.

c. Hydrolysis of Cl_2 to HCl and HOCl.

d. Neutralization of HCl.

The pHs of chlorinated effluent (Table VI, Appendix) reflected the increases in rates of caustic addition. This and measured rates of addition gave evidence that one or more of the above steps were limiting the activity of added NaOH.

Results from several mill trials (Table VI, Appendix) showed that chlorine at an application rate of 113 Kg/day (250 #/day) was effective against coliforms in secondary effluent, providing the HCl from chlorine hydrolysis was neutralized. This would require 65 Kg/day (143 #/day) of 100 percent NaOH or 130 Kg/day (286 #/day) of commercial 50 percent caustic.

EFFECT OF AMMONIA ADDITION ON CHLORINE ACTIVITY

The low cost of ammonia compared to caustic (Table 51) prompted an evaluation of its neutralizing properties. Ammonia gas at a cylinder pressure of 4.9-5.6 Kg/cm^2 (70-80 psi) was injected into the chlorinator's water system which was maintained at 1.8-2.1 Kg/cm^2 (25-30 psi). The ammonia cylinder was kept in a bucket which received a constant flow of effluent to prevent cooling of the gas and associated drop in pressure. Chlorine concentrations were calculated from the application rate and effluent flow, measured at the time of sampling. Ammonia usage was determined from periodic weighings of the cylinder. The recording effluent flow meter and point of ammonia application are shown in Figure 40.

Table 51. ESTIMATED NEUTRALIZATION COSTS WITH NaOH AND NH_3[a]

Evaluation	Neutralizing agent	
	NaOH	NH_3
Reaction	$NaOH + Cl_2 = NaCl + HOCl$	$NH_3 + Cl_2 + H_2O = NH_4Cl + HOCl$
Ratio, Base:Cl (w/w)	40:70 (50%) 80:70	17:70
Daily req., Kg (#)[a]	65 (143) (50%) 630 (286)	28 (61)
Cost		
$/Kg ($/lb)	0.0599 (0.0272)	0.0628 (0.0285)
$/Day	3.89	1.74

[a] Based on amounts required to neutralize HCl from the hydrolysis of 113 Kg/day (250 #/day) of Cl_2.

The amount of chlorine required to produce 5 minute residuals was lowered from approximately 12 ppm to approximately 6 ppm (Table 52) by the use of ammonia. However, higher concentrations were required to stop bacterial motility, 16.5-18.2 ppm with ammonia and from 19.1 to more than 21 ppm without it. Complete results from four experiments are given in Table VII, Appendix. To attain bactericidal solutions, 272 - 363 Kg/day of chlorine and 65 - 93 Kg/day of ammonia were required. The cost of chlorination would be from $39 to $50 per day. This compares with $18 per day for bactericidal solutions attained with 113 Kg/day of chlorine and 65 Kg/day of NaOH.

Figure 40. Apparatus for ammonia addition to chlorinator water supply.

Table 52. EVALUATION OF AMMONIA AS A NEUTRALIZING AGENT--SUMMARY OF MILL EXPERIMENTS

Date (1972)	Chlorine requirement, ppm				pH change due to NH_3	NH_3 added[a]	
	For 5 min resid		To stop motility				
	With NH_3	Without NH_3	With NH_3	Without NH_3		Kg/day (#/day)	% of req
May 16	6.8	12.5	--[b]	--	+0.2	10 (104)	65
May 17	--	--	18.2	19.1	0	87 (192)	99
May 18	--	--	16.3	> 21.2	+0.2	65 (144)	74
May 19	4.4	9.6-11.0	16.5	> 19.2	+0.1	93 (204)	120

[a] To provide a 5 minute residual and/or stop motility.

[b] -- Not determined.

Reactions between chlorine and ammonia to form chloramines may be partially responsible for the ineffectiveness of ammonia as a neutralizing agent. Also, as a weak base it is only 0.4 percent ionized in 0.1 M solution.[10] Only this small fraction of potentially available hydroxyl ions is available at a given instant. As reactions occur, the equilibrium is maintained and in time the full neutralizing capacity of applied ammonia may be realized. This may explain why ammonia raised the pH of effluent (Table 52) but was not effective in neutralizing acid from chlorine hydrolysis. There is not much time between the mixing of ammonia and chlorine and contact with the effluent. There is a relatively long period between the chlorination of effluent and the measurement of its pH.

In contrast, sodium hydroxide is 73 percent ionized in 0.1 M solutions.[11] Hydroxyl ions are in high concentration and available for neutralization reactions.

MODIFIED MILL CHLORINATION SYSTEM FOR USING CAUSTIC

The chemical addition port was moved from the horizontal section of the chlorinator water supply (Figure 40) to the vertical section to obtain better mixing. Because of the great distance, 244 M (800 ft), between an available caustic storage tank and the chlorinator, a double pump system was required. Caustic was pumped through 244 M (800 ft) of 1.27 cm (1/2") iron pipe to a piston pump for injection into the chlorinator's water supply. The transfer of caustic from storage was made with a Moyno pump fitted with a pressure regulator and recirculation loop to accommodate its high output.

Dimensions of the storage tank were 2.44 M in diameter and 4.24 M high (8 ft x 13.9 ft). Its capacity was 19.8 M^3 (5240 gal.). At a usage rate of 216 L/day (56.94 gal./day) of 23 percent NaOH (w/w), it provided for 91 days of continuous operation. Caustic was diluted to a 23 percent NaOH concentration to prevent it from congealing in cold weather and to improve its mixability.

The Moyno pump was fitted with a two way valve so that caustic could be pumped from the main storage tank, or from a 5 gallon bucket for measuring application rates.

METHODS FOR MONITORING CHLORINATION

As shown in Section X there are several indirect tests for estimating the effect of chlorine on coliforms, i.e., inhibition of oyxgen uptake (Oxygen Uptake Test), stopping of motile spirilla (Motility Test), and the presence of a total residual chlorine after 5 minutes contact time (5 Minute Residual Test). When effluent is chlorinated with sodium hypochlorite, there is good correlation between these tests and results obtained by standard methods for enumerating coliforms (Tables 36 and 37). Some of the benefits and disadvantages of the methods are discussed on the basis of practical experience with them.

Oxygen Uptake Test

There is a marked difference in oxygen uptake rates between unchlorinated effluent and effluent which has been adequately treated with chlorine (Figure 31). Definitive results can be obtained within 1 to 2 hours. As a laboratory test it demands considerable working time and attention. However, these drawbacks can be overcome by modifications for field use. For example, chlorinated effluent can be continuously metered into a long channel with plug flow characteristics. The channel can be calibrated in units of time for known effluent flow rates. By measuring D.O. concentrations at two points the rate of oxygen uptake can be calculated as ppm/hr. A control channel may not be necessary if unchlorinated effluent is consistent in its rate of oxygen uptake. The test made in this manner would provide information on the effectiveness of chlorination averaged over the preceeding hour or two. It would not indicate how effective chlorination is at a given instant. For this information initial and final D.O. concentrations could be determined on grab samples collected in BOD bottles.

Motility Test

This method provides results within 30 minutes and is easy to carry out in a laboratory. It does require a phase microscope to make bacteria visible without staining and is not appropriate for field use where there is a risk of rough handling and/or contamination of the optics. On rare occasions the concentrations of motile spirilla, the indicator organisms, decreased to very low concentrations in unchlorinated effluent. This made it more difficult and time consuming to evaluate the effects of chlorine. It is conceivable that even greater changes could occur making the method useless. Laboratory studies (Table 53) indicated that it is possible to carry out the test with pure cultures of motile bacteria grown in a nutrient medium. Of three species tested *Pseudomonas aeruginosa* was the most satisfactory. It grew rapidly in nutrient broth to high concentrations of motile cells. A 1:100 dilution of a 1 day old culture provided 1-10 highly motile cells, as observed under 450x magnification. The motility of *P. aeruginosa* added to secondary effluent was stopped by 10 ppm chlorine within 5 but not within 2 minutes. This is similar to the chlorine sensitivity of spirilla, the naturally occurring indicator organisms.

5 Minute Residual Test

Results from numerous trials showed that there was excellent correlation between concentrations of chlorine required to produce 5 minute residuals and those necessary to kill coliforms, providing the chlorine was added as sodium hypochlorite. When molecular (gaseous) chlorine was

Table 53. MOTILITY AND GROWTH CHARACTERISTICS OF POTENTIAL INDICATOR BACTERIA

Bacterial species	Growth medium	Amount of growth	Motile cells per field--1:100 diln, 450X
Bacillus cereus	Nutrient broth[a]	Scanty	None
Proteus mirablis	Nutrient broth[a]	Fair	None
Pseudomonas aeruginosa	Nutrient broth[a]	Abundant	1-10
	Effluent	Moderate	0.01-0.1
	Eff + 0.1% glucose	Abundant	None
	Eff + 0.1% glucose and 0.1% yeast ext	Abundant	1-10
	Nutrient broth + 0.5% glucose	Abundant	1-10

[a] Nutrient Broth, G/L of water: Beef extract 5.0; Peptone 10.0; NaCl 5.0. pH 6.8.

used, residuals could be obtained in absence of bactericidal activity. An example of this is shown for July 20, Table VI, Appendix. During mill chlorinations 9.1 ppm chlorine added as Cl_2 produced a residual of 1.7 ppm but had no effect on coliform concentrations or bacterial motility. In contrast, when caustic was added to the system, 3.9 ppm Cl produced a residual of 1.5 ppm and reduced the coliform population by 99.996 percent.

Interference by Nitrite and Iron

During evaluation of the 5 Minute Residual Test, it was found that unchlorinated secondary effluents from the aerated lagoons consistently gave negative results. However, unchlorinated effluent from the small EPA unit[*] contained an apparent chlorine concentration of more than 40 ppm. It was also noted that after titration of liberated iodine the color would gradually return and additional titrations could be made (Table 54).

A positive test for total residual chlorine depends on the oxidation of iodide to iodine by active chlorine according to the following reaction:

$$2I^- + Cl_2 \xrightarrow[\text{Starch}]{H^+} I_2 + 2Cl^- \quad \text{(Blue)}$$

The test is non-specific. Any compound capable of oxidizing iodide will give a positive result. Ferric iron and nitrite are two such interfering agents.[3] Laboratory tests showed that ferric chloride at a concentration of 1.7 ppm, as Fe, increased the apparent chlorine concentration in C.Z.[+] effluent (Table 55). However, after the first titrations there was no return of the blue starch-iodine color. Ferric iron was not the cause of the false positive tests found for EPA effluent. Nitrite at a concentration of 0.13 ppm increased the apparent

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[*] See Glossary.

[+] C.Z. -- Crown Zellerbach.

Table 54. APPARENT CHLORINE RESIDUALS IN UNCHLORINATED SECONDARY EFFLUENTS

Source of effluent	1st Titration		2nd Titration		3rd Titration	
	React time	App Cl ppm	React time	App Cl ppm	React time	App Cl ppm
Large aerated lagoons	30 sec	0	--[a]	--	--	--
	5 min	0	--	--	--	--
	1 hr	0	--	--	--	--
	3 hrs	0	--	--	--	--
EPA pilot unit	30 sec	34	1 hr	25	3 hrs	36
	5 min	41	1 hr	24	3 hrs	36
	1 hr	58	1 hr	24	3 hrs	--

[a] -- Not done.

Table 55. EFFECT OF FERRIC IRON AND NITRITE ON THE TEST FOR TOTAL RESIDUAL CHLORINE

Sample	Additive (as Fe or NO_2^-)		App Cl, ppm		Increase, moles Cl:additive
	Compound	Initial conc, ppm	1st Titr	2nd Titr	
C.Z. effluent Sept. 14, 1972	$FeCl_3 \cdot 6H_2O$	0	1.3	0	0
		0.4	1.3	0	0
		0.8	1.3	0	0
		1.2	1.3	0	0
		1.7	1.7	0	0.40
		2.1	2.6	0	0.95
		4.1	3.9	0	1.00
		8.3	6.0	0	0.90
		12.4	8.6	0	0.93
		16.5	10.8	0	0.90
River water	$NaNO_2$	0.0007	0	0	0
		0.007	0	0	0
		0.066	+[a]	--[b]	--
		0.66	5.2	--	10.0
		6.60	59.4	6.0	12.0
C.Z. effluent Sept. 14, 1972	$NaNO_2$	0.066	1.3	0	0
		0.13	2.2	0	8.50
		0.26	2.2	0	4.20
		0.39	2.6	0.40	4.20
		0.53	3.4	0.86	5.30
		0.66	3.9	1.30	5.10
		1.31	7.7	2.60	6.40
		2.63	16.4	4.30	7.50
		3.94	20.7	5.20	6.40
		5.26	24.1	6.00	5.60
EPA effluent Sept. 14, 1972	$NaNO_2$	0	36.2	6.0	0
		1.31	38.7	5.6	2.6
		2.63	42.2	3.9	3.0
		3.94	42.2	6.0	2.0
		5.26	45.6	4.7	2.3
C.Z. effluent Sept. 13, 1972	$NaNO_2$	0	1.3	0	0
		0.20	4.3	--	5.9
		1.00	16.4	--	5.9
		2.03	21.5	--	3.9
		20.20	43-86	--	1.2-1.7
EPA effluent Sept. 13, 1972	$NaNO_2$	0	37.0	--	0
		0.20	36.2	--	0
		1.00	41.3	--	1.7
		2.03	43.0	--	1.2
		20.20	103-112	--	1.3-1.5

[a] + = trace.

[b] -- Not done.

chlorine level in CZ* effluent and 0.39 ppm produced the color reversion referred to earlier. The molar ratio of apparent chlorine to nitrite was approximately 5:1 indicating the catalytic behavior of nitrite.

Approximately 5 to 10 ppm NO_2^- were required to produce the concentrations of apparent chlorine found in effluents from the EPA unit.+ Subsequent analyses of 1 day old samples by the diazotization method[3] showed that CZ effluent contained less than 1 ppb NO_2^- and EPA effluent contained 8.2 ppm. The results show that NO_2^- was responsible for the false positive tests for chlorine.

Formation of Nitrite

An effluent sample collected from the EPA unit on September 25 was found to contain only 8.5 ppm of apparent chlorine, down considerably from the 36 to 37 ppm found earlier (Table 55). This prompted a study to determine some of the factors responsible for nitrite formation which leads to the false positive tests for chlorine. Results from initial trials showed that both D.O. concentrations and effluent characteristics, most likely the nature of the bacterial population, influence nitrite formation. With continuous aeration, the apparent chlorine concentration in EPA effluent increased to 36 ppm, a value close to those previously found. The results in Table 56 are expressed as estimated nitrite concentrations. They were obtained by dividing apparent total residual chlorine by 3.85. This equivalence was determined by adding various amounts of NO_2^- to CZ effluent then measuring the increase in total residual chlorine. On this basis, aeration increased the NO_2^- concentrations in EPA effluent from 2.2 ppm to 9.4 ppm in one day and to 11 ppm within two days. Under the same conditions, the maximum concentration reached for CZ effluent was 0.68 ppm after two days, indicating a lack of nitrifying bacteria. When aeration was stopped, nitrite concentrations decreased in both effluents.

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*CZ = Crown Zellerbach.

+See Glossary.

Table 56. EFFECT OF D.O. CONCENTRATION ON THE FORMATION AND REMOVAL OF NITRITE IN SECONDARY EFFLUENT

Incubation conditions	Effluent	pH			D.O., ppm		Estimated NO_2^- ppm		
		Initial	1 Day	2 Days	Initial	1 Day	Initial	1 Day	2 Days
Still--no aeration	C.Z.[a]	7.2	7.2	7.2	4.8	1.4	0.34	0	0
	EPA[b]	7.1	7.1	7.15	5.7	1.2	2.20	0.18	0.18
Continuous aeration	C.Z.	7.2	8.0	8.1	9.0	8.9	0.34	0.57	0.68
	EPA	7.1	7.7	7.9	9.0	8.8	2.20	9.40	11.00
Continuous aeration 24 hrs then still	C.Z.	7.2	8.0	7.85	9.0	8.9	0.34	0.57	0
	EPA	7.1	7.7	7.50	9.0	8.8	2.20	9.40	4.20

[a] C.Z. = Crown Zellerbach.

[b] EPA = Environmental Protection Agency.

Nitrite levels continued to decrease in EPA effluent. On September 27 the concentration was only 0.9 ppm the same as found for effluent from the large secondary ponds (Table 57). This concentration is equivalent to an apparent chlorine residual of 3.5 ppm, and was unusual for effluent from the large ponds.

The variation in NO_2^- concentrations in effluent from the EPA unit coincided with changes in operating conditions. During periods of high NO_2^- concentrations, influent was not being added to the unit because of a pump failure. Later, when influent was added at a rapid rate to restore the normal operating volume, NO_2^- concentrations in the waste decreased. The following laboratory tests showed that nitrifying bacteria were still present in effluent from the EPA unit and indicated that NO_2^- was not being produced because of an increase in sugars due to reduced retention time.

An effluent sample collected from the EPA unit on September 27 had an estimated NO_2^- concentration of 0.9 ppm. Aeration of a sub-sample increased the NO_2^- level to 9.4 ppm within one day, showing that active nitrifiers were still present (Table 57). Another sub-sample was treated to contain 8.7 ppm NO_2^- and 0.8% (w/v) glucose. When this material was continuously aerated there was a decrease in NO_2^- to 2.3 ppm after 1 day and to 0.27 ppm after 7 days. In the same experiment it was found that effluent from the large C.Z. ponds did not contain active nitrifiers. Aeration of a sample of this material for 7 days did not lead to NO_2^- formation.

There was some evidence that bacteria from the large ponds were more active than bacteria from the EPA unit with respect to sulfite ($SO_3^=$) oxidation. When influent was inoculated with 5 percent effluent from the large ponds, $SO_3^=$ decreased from 104 ppm to 3 ppm within 1 day as compared to a decrease to 41 ppm for the same influent inoculated with 5 percent effluent from the EPA unit.

Table 57. FACTORS AFFECTING NITRIFICATION

Sample description	Additives		pH			Estimated NO_2^-, ppm				SO_3^-, ppm			
	Material	Final conc	Ini	4 D	7 D	Ini	1 D	4 D	7 D	Ini	1 D	4 D	7 D
EPA effluent collected 9/27/72	None	0	7.3	7.3	6.2	0.90	9.4	12.8	10.1	1.8	3.2	2.1	2.6
	Na_2SO_3	17 ppm	7.5	7.4	6.7	0	8.1	11.6	13.0	17.0	2.9	2.3	2.9
	$NaNO_2$ glucose	8.0 ppm 0.8%	6.9	5.0	4.8	8.70	2.3	0.90	0.27	1.8	3.0	2.5	3.9
	Secondary inf	10%	7.3	7.6	7.4	0	6.9	12.1	12.8	9.2	2.6	2.4	2.4
C.Z. effluent collected 9/27/72	None	0	7.2	8.0	8.0	0.90	0.67	0.58	0.67	1.8	3.2	2.5	2.4
	EPA eff (9/25)	1.0%	7.2	7.9	7.8	0.90	0.49	0.78	0.78	1.8	2.9	3.0	2.9
Secondary influent 9/27/72	C.Z. eff (9/27)	5.0%	7.3	7.7	7.6	0	0	0.40	0.49	104	3.2	2.3	2.5
	EPA eff (9/25)	5.0%	7.1	7.6	7.6	0	0	0.40	0.40	104	41	2.0	2.3

The preceeding shows that wastes being treated in the two types of ponds differed biochemically. It was found that they also differed in other ways. Turbidity in effluent from the large ponds did not decrease upon standing. In marked contrast, the particles responsible for turbidity in effluent from the EPA unit settled rapidly.

Microscopic observations showed further differences between the effluents. Numerous fibers were observed in effluent from the EPA unit but few in the waste from the large ponds. Figure 9 illustrates the differences seen in the microbial populations. Effluent from the large aerated ponds contained a diverse group of bacteria which were well dispersed. Bacteria in effluent from the EPA unit were concentrated within partially degraded fibers or in zoogleal masses.

Nitrite also may be formed in soils by the bacterial oxidation of NH_4^+ from commercial fertilizers or from animal wastes. Under anaerobic conditions, other types of bacteria can reduce nitrate to NO_2^-. Leaching and runoff from soils are two mechanisms by which NO_2^- could enter streams.

Significance of Nitrite

Negative results from tests for total residual chlorine are conclusive. However, positive results under suspect conditions will require further checking because of possible nitrite interference. In the quantitative analysis for total residual chlorine, if the blue color of the starch-iodine complex returns after an end point has been reached, this may indicate nitrite interference. In this case total residual chlorine analyses of samples taken upstream and downstream from an effluent discharge point will indicate the importance of the waste as a source of residual chlorine and/or NO_2^-.

False positive tests for total residual chlorine have been obtained frequently for samples of effluent treated with molecular chlorine or chlorine dioxide but rarely for samples treated with sodium hypochlorite. This may have been due to oxidation of NH_4^+, which is present in the effluent, to NO_3^- by the stronger oxidizing agents.

pH Measurements

Successful operation of the modified chlorination system depends on the conversion of Cl_2 to HOCl and/or NaOCl by NaOH addition. Two rapid methods were used to monitor neutralization reactions:

a. pH measurements were made on injector water sampled downstream from the point of NaOH addition. Experience showed that when pHs were in the range of 11.5 to 12.5 an adequate amount of NaOH was being used. Fluctuations in pH were usually caused by variations in water flow due to variable use in the mill. pHs less than 11.5 frequently were caused by decreases in NaOH addition rates due to mechanical problems.

b. pH measurements were made on effluent samples before and after chlorination. With adequate caustic addition they were the same. This proved useful in establishing the correct rate of caustic application for a constant rate of chlorination.

FACTORS AFFECTING FULL SCALE CHLORINATION

Concentrations of Lignosulfonates

Results from laboratory studies (Table 47) indicated that variations in the concentrations of lignosulfonates could influence chlorine requirements. To evaluate this further, samples of effluent were centrifuged at 9750 xg for 15 minutes to remove particles. The supernatant was diluted 1:10 and U.V. absorbance of the diluted samples was measured at 280 nm to estimate lignosulfonate levels. The mean U.V. absorbance for 12 samples was 2.75 ± S.D. 0.19 (Table 58).

Table 58. VARIATIONS IN ULTRAVIOLET ABSORBANCE AND FLOW RATES OF SECONDARY EFFLUENT

Date (1972)	Time	U.V. abs @ 280 nm	Eff flow l/sec (TGH)
June 21	1700	3.20	--[a] (--)
July 5	1140	2.60	147 (140)
5	1145	2.80	-- (--)
6	1630	3.00	304 (290)
7	1240	2.75	310 (295)
7	1350	2.65	236 (225)
8	0800	2.70	284 (270)
8	1540	2.55	257 (245)
8	2100	2.65	307 (292)
10	1540	2.70	215 (205)
11	1445	2.75	131 (125)
Aug. 7	1217	2.60	315 (300)
Mean	--	2.75	251 (239)
S.D.	--	0.19	68 (64)
Var., %	--	6.9	27 (27)

[a] -- Not determined.

The difference between extremes was 0.40 or approximately 14 percent. This rather limited evaluation indicates that fluctuations in lignosulfonate concentrations would not be a major factor in chlorination. However, combined with other effects such as flow rate variations it could become significant.

Series vs Parallel Operation

After three days of series operation, effluent samples from Ponds 1 and 2 were evaluated for chlorine requirements. The requirements for Pond 2 were similar to those of combined effluent from parallel operation. Between 8 and 10 ppm stopped bacterial motility and approximately 2 ppm provided a 5 minute residual (Table 59).

Table 59. CHLORINE REQUIREMENTS OF PONDS 1 AND 2 IN SERIES OPERATION. 9/16/72

Chlorine added, ppm	5 Min chlorine residual, ppm		Motile spirilla per field @ 30 min	
	Pond 1	Pond 2	Pond 1	Pond 2
0	0	0	1-10	1-10
2	0	0.43	1-10	1-10
4	0	0.86	1-10	0.1-1.0
6	0	1.90	1-10	0.1-1.0
8	0	3.00	1-10	0.01-0.1
10	0	4.00	1-10	0
20	0	9.00	1-10	0
40	0	20.00	1-10	0
60	0	42.00	1-10	0
80	0	45.00	1-10	0
100	1.7	49.00	1-10	0
120	9.4	--[a]	0	--

[a] -- Not determined.

In contrast, for Pond 1 approximately 100 ppm chlorine were required to produce a residual and between 100 and 120 ppm to stop motility. This high requirement was due to the higher $SO_3^=$ concentration in Pond 1, 71.5 ppm compared to 0.51 ppm for Pond 2. A concentration of 71.5 ppm $SO_3^=$ is equivalent to 63 ppm chlorine. The amount required in excess of this for Pond 1 effluent may have been due to more complete and rapid reactions between chlorine and lignosulfonates at high chlorine levels. The significance of sulfite in secondary wastes is also discussed in Section X.

Results from mill trials made after one week of series operation showed that 4.9 ppm chlorine reduced coliforms by 99.998 percent providing caustic was added to the chlorinator's water supply (Table 60). Without caustic addition the effective concentration was between 21 and 27 ppm.

During series operation spot checks were made to determine the effect of standard chlorination (113 Kg/day Cl plus NaOH addition) on bacterial motility. Results at the start of series operation and after 3 and 12 days (Table VIII, Appendix) showed that motility was stopped by 6.0-7.1 ppm chlorine.

The results show that effluent from series operation can be effectively treated with the same concentrations of chlorine as required for effluent from parallel operation. However, there is a situation where the chlorine requirement would be increased tremendously and perhaps should not be attempted. This would be during the early periods of change over from series to parallel operation. Due to the decreased retention time in the first pond $SO_3^=$ concentrations will increase. This is no problem as long as series operation is continued because $SO_3^=$ is reduced to low levels in the second pond and it is only the effluent from Pond 2 which receives chlorine. After changing to parallel, the $SO_3^=$ concentration will remain high in Pond 1 for a considerable period. During this time the unchlorinated effluent from Pond 1 with its high $SO_3^=$ level will immediately neutralize chlorine residuals as it mixes with the chlorinated effluent from Pond 2 (See Figure 37).

Injector Water Pressure

At Lebanon the pressure in the injector water line fluctuated in response to water usage in the mill. For example, on November 14, 1972 the

Table 60. MILL CHLORINATION OF SECONDARY EFFLUENT FROM SERIES OPERATION WITH AND WITHOUT CAUSTIC ADDITION

Chlorine added		NaOH added	Eff pH	5 min Cl res, ppm	Motile sp per field	Coliforms 100 ml	Colif redn, %
Kg/day (#/day)	ppm						
0	0	No	7.3	0	1.0-10.0	44×10^5	--[a]
91 (200)	5.4	No	7.0	1.0	0.1-1.0	46×10^5	0
182 (400)	10.8	No	6.8	1.6	0.1-1.0	31×10^5	29.546
272 (600)	16.2	No	6.5	2.2	0.1-1.0	18×10^5	59.091
363 (800)	21.0	No	6.6	3.4	0.01-0.1	3×10^5	93.182
454 (1000)	27.0	No	6.5	4.6	0	< 100	> 99.998
(100)	2.4	Yes	7.3	0	0.01-0.1	54×10^3	98.773
91 (200)	4.9	Yes	7.2	1.0	0.01-0.1	100	99.998
113 (250)	6.0	Yes	7.2	1.6	0	100	99.998
182 (400)	9.5	Yes	7.1	4.6	0	< 100	> 99.998
272 (600)	14.3	Yes	7.0	4.7	--	--	--
363 (800)	18.9	Yes	7.0	10.4	--	--	--
454 (1000)	23.8	Yes	6.9	7.0	--	--	--

[a] -- Not determined.

pressure varied from 1.3 to 2.6 Kg/cm^2 (19-37 #/in.^{2}). During the same period caustic use varied from the equivalent of 181 to 286 Kg/day (400-630 #/day). An adjustable pressure regulator valve was installed in the water line so that caustic could be pumped into the system against a constant resistance. Tests made on November 21 and 22, 1972, showed that caustic usage was approximately 136 Kg/day (300 #/day) when pumped against a total pressure (water plus regulator) of 1.76-1.90 Kg/cm^2 (25-27 #/in.^{2}). When the total pressure was increased to 2.1 Kg/cm^2 (30 #/in.^{2}) or more caustic usage decreased to approximately 72 Kg/day (160 #/day) and was independent of pressure up to 4.2 Kg/cm^2 (60 #/in.^{2}).

The results are presented to show that caustic use can be influenced by variations in head pressure. The importance of this problem will vary according to pump characteristics and the magnitude of water pressure variations. If insufficient caustic is added to the system, normal amounts of chlorine will be inadequate. If too much caustic is used the processes will be more expensive than necessary and chlorine residuals may persist for too long a time due to increased effluent pH and decreased chlorine activity at the zone of contact.

Effluent Flow Rate

Seventy effluent flow readings were taken during the monitoring of full scale chlorination from July 18 through November 25, 1972. The mean was 228 ± S.D. 33 l/min (217 ± S.D. 31 TGH). This represents a variance of 14 percent (Table VIII, Appendix). Since the chlorination rate was held constant this caused similar fluctuations in the concentration of applied chlorine. Extremes in effluent flow were 131 l/min and 304 l/min (125 and 290 TGH). At the constant chlorination rate of 113 Kg/day (250 #/day) this resulted in initial chlorine concentrations of 4.3 ppm and 10.0 ppm respectively.

The cyclic variation in effluent flow rates is shown on the continuous recorder in Figure 40. These are related to the batch pulping process with intermittent discharge and washing. Wider variations often occurred in response to shifting wind velocity and direction over the ponds. Extremes ranged from no effluent flow to more than 315 l/min (300 TGH), the highest calibration on the flow meter.

These conditions clearly indicate the need for a chlorination system which will respond to changes in effluent flow to maintain a constant initial chlorine concentration. Similar control would also be required for the caustic addition system. Without it two undesirable conditions could develop:

Chlorine Addition Rate Increases in Response to Greater Effluent Flow Rate -- Without a similar increase in caustic application, neutralization of chlorine hydrolysis products would be incomplete. Molecular chlorine would react rapidly with lignosulfonates and would not provide enough chlorine residual to kill coliforms.

Chlorine Addition Rate Decreases in Response to Reduced Effluent Flow -- Here NaOH would be present in excess and chlorine could be converted completely to NaOCl. Initial reactions with lignosulfonates would be relatively slow, leading to high concentrations of residual chlorine. Reactions from here on would be related to the pH of chlorinated effluent. If on the acid side, bactericidal activity would be excellent and a relatively rapid reaction rate might make this condition acceptable. If the effluent were on the alkaline side, and excess NaOH would favor this, bactericidal activity would be low and chlorine residuals could persist for undesirably long intervals. This suggests the possibility of toxicity in receiving waters if there is a shift in pH upon dilution from a moderately alkaline waste to a neutral mixture. The chlorinating procedure described, however, has a built in safeguard against this. The amount of caustic used is sufficient to neutralize only half of the acids produced from the hydrolysis of chlorine.

From the standpoint of effectiveness, added protection against stable chlorine residuals and efficiency of operation, it would be desirable to vary both chlorine and caustic addition in response to changes in effluent flow rates. A system to do this has been designed but had not been evaluated at the time of writing.

Primary Pond Operation*

The main function of the primary pond is to remove fibers and other particles from mill wastes before they go to secondary treatment. When the pond is nearly full of accumulated sediment or when it is being pumped, unsettled waste enters the secondary treatment ponds and the concentration of particles increases in secondary wastes. This apparently has no adverse effect on chlorination. For example, during the period from September 14 to 22, 1972, the primary pond was nearly full or out of service. Chlorination of secondary effluent during this time was effective as shown by the Motility Test+ (Table VIII, Appendix). However, during the period of inadequate primary treatment, there was a change in the stability of total residual chlorine.

In chlorinated effluent samples total residual chlorine consistently persisted for longer than 2 hours which was unusual. Further tests showed that unchlorinated effluents also gave positive tests and that concentrations of 2 hour residuals were similar for chlorinated and unchlorinated samples. The reason for the false positives was not

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*Also see Section IV, Apparatus and Methods.
+See Section X, Activity of Chlorine in Secondary Wastes.

determined. However, the results do suggest an interesting possibility. In the subsection, METHODS FOR MONITORING CHLORINATION, nitrite formation in the small EPA pilot unit was described. It was found that nitrite in the effluent catalyzed the oxidation of I^- to I_2 and in so doing gave a false positive test for total residual chlorine. One of the ways in which the operation of the EPA unit differed from that of the large ponds was that influent for the small unit received no primary (settling) treatment. During the period in question here, influent to the large secondary ponds also had inadequate or no primary treatment. For a period, influent to both C.Z. and EPA units were the same. This suggests that the presence of fibers and/or other suspended particles leads to the development of a microbial population capable of nitrification during secondary waste treatment. For proof of this, however, effects of high D.O. levels, low BOD and retention time on nitrification would have to be resolved. It is apparent that the types of bacteria developing on fibers in the EPA unit differ considerably from the population normally found in the large treatment ponds (Figure 9).

MONITORING OF FULL SCALE CHLORINATION

Procedure

The conditions established for effective chlorination included a chlorine application rate of 113 Kg/day (250 #/day) and a caustic addition rate of 65 Kg/day (143 #/day), based on 100 percent NaOH. The system was checked frequently to determine how well these conditions were maintained. Chlorine and caustic additions were then adjusted to the desired rates, if necessary, and bactericidal activity was estimated with the Motility Test.*

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*See Section X.

Chlorine Application Rate

The chlorine delivery rate required few adjustments and was seldom off more than 1 to 2 Kg/day or ± 1-2 percent of the desired rate.

Caustic Delivery Rate

The mean application rate was 81 Kg/day (178 #/day) which was approximately 24 percent more than desired (Table VIII, Appendix). Variance for 70 measurements was 37 percent. This was due mainly to experiments with caustic flow rates and to pump problems. For example, on September 18 a failure of the Moyno pump allowed water from the chlorinator's injector line to partially fill the caustic tank. A check valve was installed to prevent this from occurring again and the pumping rate was increased to compensate for the dilution of caustic.

Data in Table VIII, Appendix, show caustic use only at the time of monitoring for bactericidal activity. Measurements taken at other times showed that pumping rates were affected by fluctuations in injector water pressure. Both impeller type and piston pumps were sensitive to this. As mentioned previously, an adjustable pressure regulating valve was installed later so that the pump would be working against a constant resistance. Time did not permit a complete evaluation of this modification.

Bactericidal Activity

With only one exception chlorination completely stopped motility of spirilla and on July 20 (Table VIII, Appendix) their concentrations were lowered from 1-10 per field to 0.01-0.10 per field. As shown in Section X this is a good indicator of adequate coliform kill.

Factors Contributing to 2 Hour Chlorine Residuals

An optimum chlorination procedure would be one which provided sufficient chlorine to kill coliforms and produce a positive test for chlorine residual at 5 minutes but not after 2 hours. The first critereon was met. However, 41 percent of the 70 samples tested gave a positive test for chlorine after 2 hours. As mentioned in the previous section, even unchlorinated samples gave positive chlorine tests during the period of inadequate primary treatment. When the results from this questionable period were removed, new calculations showed that 16 out of 57 samples, 28 percent, gave positive tests for 2 hour Cl residual (Table 61). The following factors could lead to stable residuals:

a. High initial chlorine concentrations due to reduced effluent flow with a constant rate of chlorination.

b. High caustic addition rates.

c. Low injector water pressure which would lead to increased caustic addition.

d. High effluent pH.

There was little difference in the mean values of these characteristics for samples which had 2 hour chlorine residuals and those which did not.

When values for individual samples which had 2 hour residuals are compared with the means of samples which did not, possible causes for the stable residuals become apparent (Table 62), in some instances. In 3 of the 16 samples with 2 hour residuals initial chlorine concentrations were from 22 to 72 percent greater than the mean of samples without 2 hour residuals. In 3 other samples higher than normal caustic addition rates or low injector water pressure was related to stable residuals. Possible reasons for stable residuals in the other 10 samples were not apparent.

Table 61. SUMMARY OF FULL SCALE CHLORINATION MONITORING DATA

Sample description	Chlorine added			Cl resid, ppm		NaOH added		Eff flow		Inj H_2O Press.		Eff
	Kg/day	(#/day)	ppm	5 Min	2 Hr	Kg/day	(#/day)	L/sec	(TGH)	Kg/cm^2	(#/in.^{2})	pH
All samples												
Mean	113	(250)	5.9	2.4	0.5	81	(178)	228	(217)	3.8	(54)	7.0
S.D.	0		1.0	0.8	0.7	30	(66)	33	(31)	1.1	(15)	0.2
Var., %	0		17	33	140	37		14		28		--[a]
# of samples	70		70	63	68	66		70		70		50
All samples with 2 hr Cl residual												
Mean	113	(250)	6.1	2.7	1.1	74	(163)	223	(212)	3.7	(53)	7.0
S.D.	0		1.3	1.0	0.7	21	(46)	36	(34)	1.0	(14)	0.2
Var., %	0		21	37	64	28		16		26		--
# of samples	29		29	28	29	27		29		29		26
All samples with no 2 hr Cl residual												
Mean	113	(250)	5.8	2.1	0	80	(177)	228	(217)	3.7	(52)	7.0
S.D.	0		0.6	0.5	0	23	(51)	27	(26)	1.1	(16)	0.2
Var., %	0		10	24	0	29		12		31		--
# of samples	34		34	34	34	32		34		34		29

[a] -- Not calculated.

Table 61 (continued). SUMMARY OF FULL SCALE CHLORINATION MONITORING DATA

Sample description	Chlorine added			Cl resid, ppm		NaOH added		Eff flow		Inj H_2O Press.		Eff
	Kg/day	(#/day)	ppm	5 Min	2 Hr	Kg/day	(#/day)	L/sec	(TGH)	Kg/cm^2	($\#/in.^2$)	pH
All samples except 9/14-10/7												
Mean	113	(250)	5.9	2.3	0.2	84	(186)	227	(216)	3.9	(56)	7.0
S.D.	0		0.9	0.6	0.4	22	(48)	30	(29)	1.1	(15)	0.3
Var., %	0		15	26	200	26		13		27		--[a]
# of samples	57		57	50	55	54		57		57		47
Samples with 2 hr Cl resid except 9/14-10/7												
Mean	113	(250)	6.3	2.4	0.7	80	(176)	219	(208)	4.2	(60)	70
S.D.	0		1.2	0.8	0.4	10	(22)	33	(31)	0.97	(14)	0.3
Var., %	0		19	33	57	13		15		23		--
# of samples	16		16	15	16	15		16		16		13
Samples with no 2 hr Cl resid except 9/14-10/7												
Mean	113	(250)	5.8	2.1	0	80	(177)	228	(217)	3.7	(52)	7.0
S.D.	0		0.6	0.5	0	23	(51)	27	(16)	1.1	(16)	0.2
Var., %	0		10	24	0	29		12		31		--
# of samples	34		34	34	34	32		34		34		29

[a] -- Not calculated.

Table 61 (continued). SUMMARY OF FULL SCALE CHLORINATION MONITORING DATA

Sample description	Chlorine added			Cl resid, ppm		NaOH added		Eff flow		Inj H_2O Press.		Eff
	Kg/day	(#/day)	ppm	5 Min	2 Hr	Kg/day	(#/day)	L/sec	(TGH)	Kg/cm^2	$(\#/in.^2)$	pH
Samples of 9/14-10/7 (All had 2 hr Cl resid)												
Mean	113	(250)	5.8	2.8	1.6	65	(144)	234	(223)	3.1	(44)	7.1
S.D.	0		1.4	1.2	0.7	27	(60)	38	(36)	0.5	(6.6)	0.2
Var., %	0		24	43	44	42		16		15		--[a]
# of samples	13		13	13	13	12		13		13		13
Unchlor eff (All samples) 9/14-10/7												
Mean	0	(250)	0	0.9	0.8	0		230	(219)	3.2	(46)	7.0
S.D.	0		0	0.9	0.8	0		46	(44)	0.2	(2.6)	0.1
Var., %	0		0	100	100	0		20		6		--
# of samples	9		9	9	9	9		9		9		9
Unchlor eff 9/14-10/7 with 2 hr Cl resid												
Mean	0	(250)	0	1.7	1.4	0		255	(243)	3.2	(46)	7.0
S.D.	0		0	0.3	0.5	0		28	(27)	0.2	(3)	0.1
Var., %	0		0	18	36	0		11		7		--
# of samples	5		5	5	5	5		5		5		5

[a] -- Not calculated.

Table 62. CHARACTERISTICS OF EFFLUENTS WITH 2 HOUR CHLORINE RESIDUALS

Date (1972)	Additions		Eff pH	Inject. H_2O press., Kg/cm^2	Variations from mean[a]				Cl resid, ppm @		Δ Cl/2 hrs	
	Cl ppm	NaOH Kg/day			Cl add., %	NaOH add., %	Eff pH, units	Inject H_2O press., %	5 Min	2 Hrs	ppm	% of 5 Min res
July 21	5.0	98	6.6	4.9	-14	+22	-0.4	+17	1.2	0.5	0.7	58
27	10.0	98	--[b]	4.9	+72	+22	--	+17	--	1.2	--	--
31	6.0	73	6.7	4.2	+ 3	- 8	-0.3	0	2.8	1.2	1.6	57
Aug. 2	6.1	82	6.8	5.1	+ 5	+ 2	-0.2	+21	3.3	0.7	2.6	79
3	6.0	82	6.9	4.6	+ 3	+ 2	-0.1	+10	1.8	0.7	1.1	61
9	6.4	82	6.8	4.9	+10	+ 2	-0.2	+17	2.0	0.5	1.5	75
10	6.4	82	6.8	5.1	+10	+ 2	-0.2	+21	2.0	0.5	1.5	75
17	7.6	82	7.2	4.	+31	+ 2	+0.2	+17	3.8	1.6	2.2	58
17	6.1	82	7.2	4.9	+ 5	+ 2	+0.2	+17	3.2	0.3	2.9	91
20	5.6	82	--	4.6	- 3	+ 2	--	+10	4.0	1.0	3.0	75
22	5.4	82	7.3	4.6	- 7	+ 2	+0.3	+10	2.7	0.3	2.4	89
24	5.4	82	--	4.2	- 7	+ 2	--	0	2.3	1.2	1.1	48
Oct. 9	5.2	65	7.0	2.8	-10	-18	0	-33	2.0	0.3	1.7	85
10	6.4	59	7.2	2.8	+10	-26	+0.2	-33	2.6	0.7	1.9	73
Nov. 13	7.1	--	7.7	2.6	+22	--	+0.7	-38	2.7	0.6	2.1	78
16	6.0	72	7.1	2.4	+ 3	-10	+0.1	-43	2.4	0.6	1.8	75

[a] Mean of samples with no 2 hour chlorine residual.

[b] -- Not determined.

EFFECT OF CHLORINATION ON RECEIVING WATERS

Procedure

Coliform analyses were made on samples collected from the following sites:

Cement Plant - On the South Santiam River upstream from the mill and city effluent discharge points.

Mark Slough Bridge - 304 m (334 yd) downstream of mill discharge. The slough may be 50 percent or more effluent depending on water flow from an upstream dam.

Mark Slough Mouth - 1.22 Km (1334 yd) downstream at the entrance to the South Santiam River.

Pipeline Crossing - 4.83 Km (3 mi) downstream on the South Santiam River.

Sanderson's Bridge - 12.9 Km (8 mi) downstream.

Analyses for dissolved oxygen, pH and temperature were made at the sampling site.

Coliforms

Prior to chlorination the mean coliform count was 5.7 million/100 ml at Mark Slough Bridge and 4.2 million/100 ml at the mouth of the slough (Table 63). Chlorination reduced concentrations but its effectiveness was variable (Figure 41). For example on July 18 and 27 and on August 24 coliform concentrations at the mouth of the slough were similar to those found before chlorination. In contrast, during the last few days of August, counts in the slough were reduced to levels approaching those found in the river upstream from the mill discharge,

Table 63. EFFECT OF CHLORINATION ON RECEIVING WATERS. SUMMARY OF DATA

Analysis	Sample points and treatment of effluent									
	Cement plant		M.S. bridge		M.S. mouth		Pipeline crossing		Sanderson's bridge	
	None	Chlor	None	Chlor	None	Chlor	None	Chlor	None	Chlor
pH										
Mean	7.2	7.44	6.70	7.11	6.83	7.13	7.10	7.32	--[b]	7.35
Range	--	6.9-8.2	6.3-7.3	6.7-7.6	6.4-7.4	6.6-7.7[a]	--	7.0-8.2	--	6.9-8.1
# of tests	1	14	6	14	6	15[a]	1	14	0	13
D.O., ppm										
Mean	--	10.5	5.82	7.00	2.45	3.10	--	8.85	--	9.41
Range	--	10.0-11.4	3.6-6.9	4.7-9.0	0.4-5.4	1.2-7.1	--	4.9-10.8	--	8.4-10.8
# of tests	0	11	4	12	4	12	0	11	0	12
Temp, °C.										
Mean	16.5	18.3	21.0	22.0	22.2	22.4	16.8	18.7	--	20.2
Range	--	13.7-23.0	18.6-25.0	16.0-26.4	21.3-24.3	15.6-29.4	--	16.0-23.8	--	14.9-24.8
# of tests	1	13	6	14	6	14	1	13	0	12
Cl resid, ppm										
Mean	--	0.92	0	0.27	0	0.12	--	0.50	--	0.56
Range	--	0-3.6	0	0-1.1	0	0-1.1	--	0-1.2	--	0-1.6
# of tests	0	9	5	10	5	12	0	9	0	10
Colif/100 ml X 10^5										
Mean	0.002	0.003	56.8	5.27	42.5	12.80	0.230	0.150	--	0.074
Range	--	0.001-0.002	30-140	0.005-54.0	13-110	0.001-120	--	0.001-0.860	--	0.001-0.65
# of tests	1	15	6	15	6	17	1	16	0	15

[a] Excluding abnormal value of 4.8 on June 30.

[b] -- Not determined.

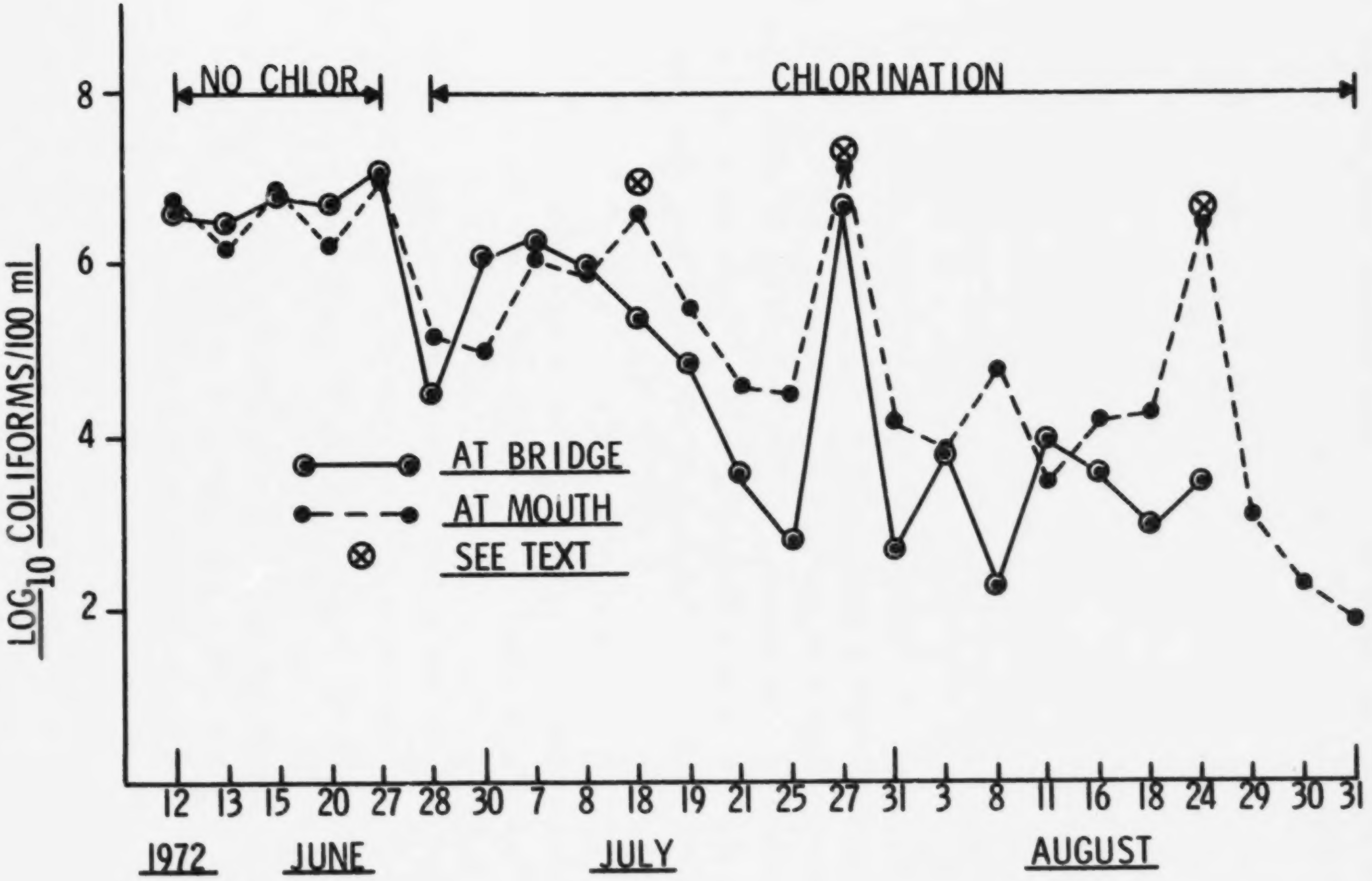

Figure 41. Effect of chlorination on concentrations of coliforms in Mark Slough.

between 100 and 1000 coliforms/100 ml. These and all other analytical data are presented in Table IX, Appendix.

The occasions of poor chlorination performance were found to be due to pump failures which allowed primary effluent to be discharged into the slough. The relatively high sulfite content of this waste would immediately inactivate chlorine residuals. When these periods of abnormal operation are not considered, the reduction of coliforms in the slough by chlorination was 96.0 percent. For the last 10 days of normal operation, coliforms were reduced by 99.65 percent from prechlorination levels.

The effects of chlorination were also seen in samples taken 3 miles and 8 miles downstream from the mouth of the slough (Figure 42). Changes in coliform concentrations in the river paralleled those found in samples from the mouth of Mark Slough. High coliform populations again were due to the inactivation of chlorine by influent discharged to the slough.

During the last 7 days of the tests coliform concentrations were greatly reduced in the slough by effective chlorination. This was reflected by similar changes in the river. From August 29-31 coliform levels in the river at both downstream sampling points were approximately the same as those found upstream from the slough, 50-170 coliforms/100 ml (Table IX, Appendix).

It was interesting to find that during periods of ineffective or marginal chlorination there was approximately a 2 log unit difference between coliform populations in the slough and river. This approximates the effluent dilution rate in the river and indicates that the effluent is the major source of coliforms. As chlorination became more effective, the populations became closer in number. Near the end of the test,

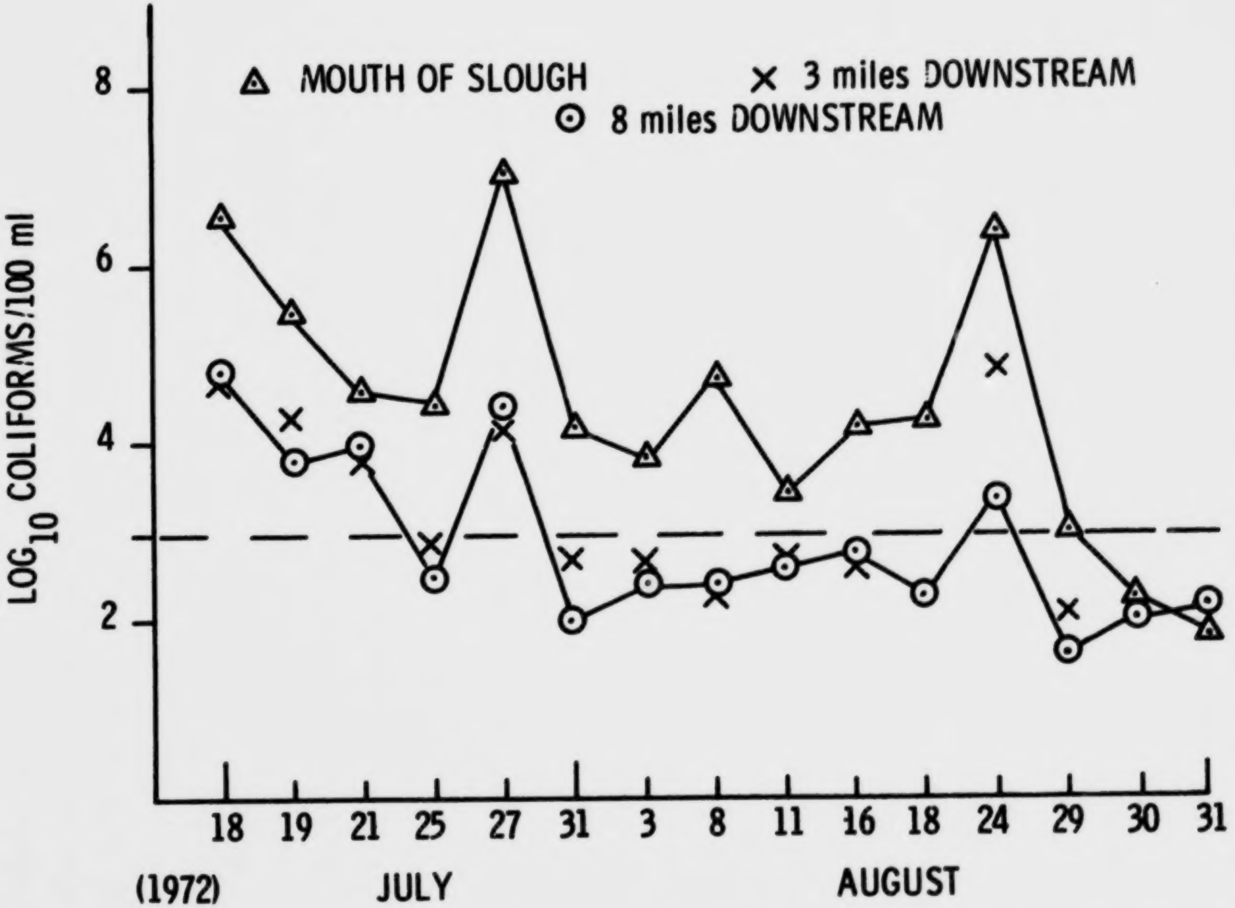

Figure 42 Reduction of coliform concentrations in the South Santiam River due to chlorination of secondary effluent.

coliform concentrations were equivalent in the slough and river showing that effluent discharge was not significantly affecting the coliform population in the river.

Dissolved Oxygen

As effluent is discharged from the secondary treatment ponds it absorbs oxygen by falling in thin films over weirs and by turbulence. At the point of discharge into the slough it may contain 7 to 8 ppm D.O. As the waste flows down the slough, D.O. concentrations are reduced by the activity of microorganisms. In laboratory experiments with undiluted effluent, the rate of oxygen uptake was found to be approximately 2 ppm D.O./hr (Table 37). In the slough the rate could be less than this due to the effects of dilution water which spills over a dam upstream from the point of effluent discharge. However, most of the time the rate of oxygen uptake in the slough or the D.O. concentration at the mouth of the slough can be used as an indication of the effectiveness of chlorination. This is a field application of the laboratory test, Oxygen Uptake Test, discussed in Section X. In this case, D.O. measurements at the mouth of the slough provide a more convenient index.

Under normal operating conditions the mean of 3 determinations, made at the slough mouth before chlorination, (Table IX, Appendix) was 1.5 ppm with a range of 0.4-2.6 ppm. During chlorination the mean of 7 samples, taken during normal operation, was 4.5 ppm with a range of 3.0-7.1 ppm. The same conditions which affected coliform counts affected D.O. levels. When influent flowed into the slough and inactivated chlorine residuals, July 18, 27 and August 24, microbial activity reduced D.O. concentrations to prechlorination levels (Figure 43). The reason for the low D.O. concentration on August 8 was not determined but it coincided with an increase in coliforms (Figure 41).

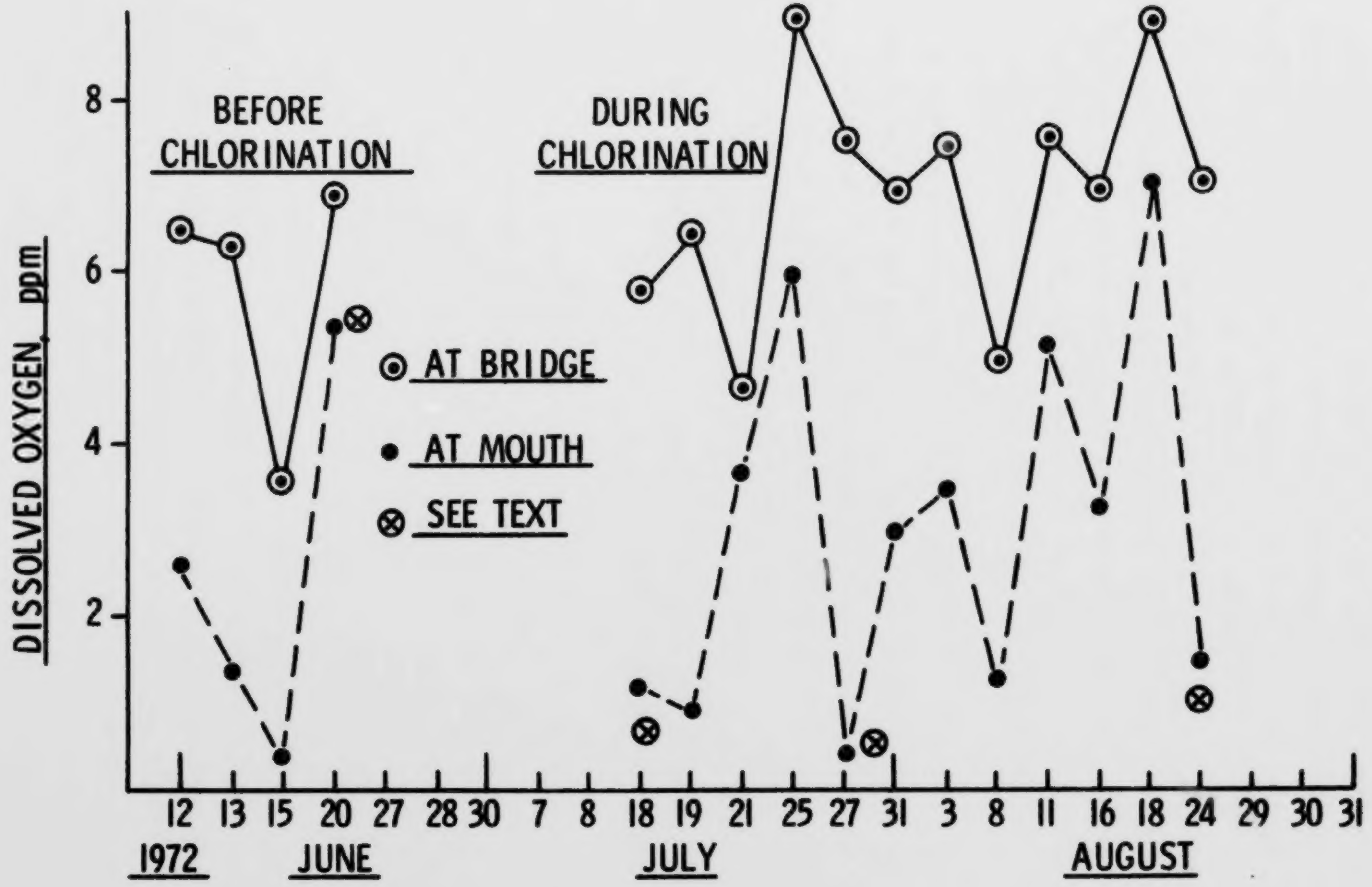

Figure 43. Effect of chlorination on D.O. in Mark Slough.

D.O. measurements also proved to be a sensitive indicator of unusual conditions occurring during secondary treatment. On June 20, prior to chlorination, the D.O. concentration at the mouth of the slough was 5.4 ppm. This unusually high value was related to low effluent pH. Measurements taken on June 21 showed that effluent from Pond 1 had a pH of 5.6 and that from Pond 2, 4.8. Previous laboratory experiments (Table 37) showed that oxygen uptake by secondary effluent in this pH range was 32 percent less than at the usual pH of 7.0. The pH value 6.8 obtained at the mouth of the slough on June 20 is questionable.

Fluctuations of D.O. in the slough had their corolaries in the river. Although the river 8 miles downstream consistently had more than 8 ppm D.O., the times of lowest concentrations corresponded to those when D.O. was lowest in the slough (Figure 44). D.O. levels 3 miles downstream were 7.7 ppm and 4.9 ppm on July 18 and 19, respectively. This was considerably lower than found in the samples taken further downstream. On all of the other sampling days D.O. concentrations were the same at the 3 mile and 8 mile locations.

The reduction of D.O. in the river by effluent discharge is not due to the low D.O. of the effluent *per se* but rather to the large bacterial population which caused it. The amount of D.O. decrease will depend on the concentration of bacteria and the BOD of the diluted effluent.

pH

Chlorination should have no effect on the pH of receiving waters because of the small amount of chlorine used and the neutralization of chlorine hydrolysis products with caustic. Any effects due to abnormal chlorinating conditions were not detected. It was noted, however, that factors upstream from the effluent discharge point had a significant effect on the pH of the river. For example, on July 21 and August 31 the pH of the river, measured at the cement plant, was approximately 8.

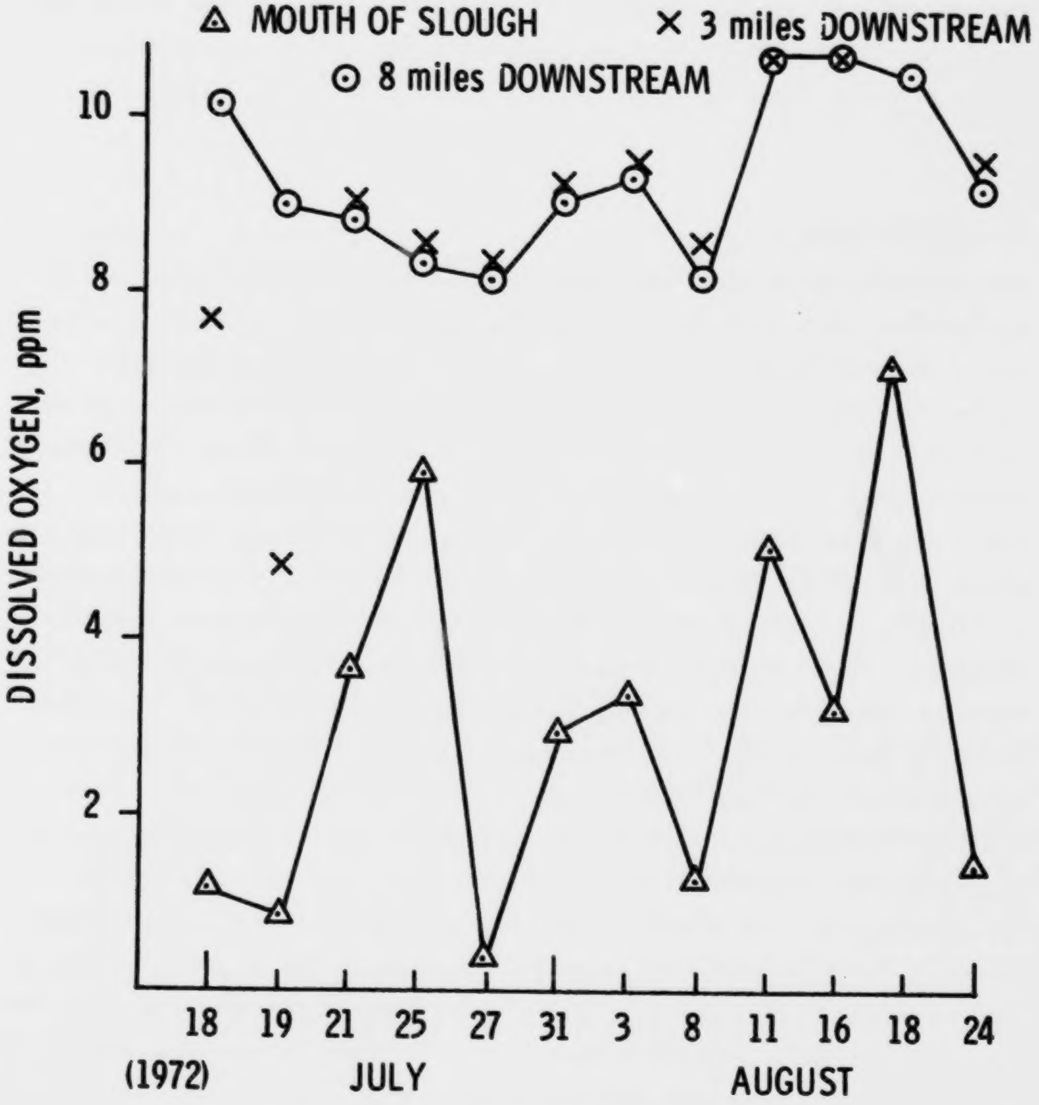

Figure 44. Effect of chlorination of secondary effluent on D. O. concentrations in the South Santiam River.

The pHs of effluent at the mouth of the slough were 7.2 and 7.4 on the two days. Three miles and 8 miles downstream, the river reflected the higher pHs found upstream of the effluent discharge (Table IX, Appendix).

Chlorine Residuals

Positive tests for total residual chlorine were obtained for 3 out of 15 samples taken at Mark Slough Bridge and for 2 out of 15 from the mouth of the slough (Table IX, Appendix). On these days positive residuals also were found at the two downstream sampling points in the Santiam River. There may not have been a cause and effect relationship, however, as positive results were frequently obtained for samples taken upstream from Mark Slough. This was at the Cement Plant site which also was upstream from the Lebanon's City Sewage Treatment Plant, a potential source of chlorine residuals. On four occasions positive tests were found at the Pipeline Crossing and at Sanderson's Bridge when no residuals were detected at the mouth of the slough. On August 8 and 11 total residual chlorine was found at Sanderson's Bridge but none could be detected upstream at the Cement Plant site or at the mouth of Mark Slough. The results indicate that factors other than chlorine were responsible for the positive tests. The presence of nitrite in the river water is one possible cause. Laboratory studies (Table 55) showed that 0.066 ppm NO_2^- in water gives a positive test for total residual chlorine. Possible sources of nitrite would include the application of inorganic fertilizers followed by leaching and/or runoff. Under the proper conditions microorganisms can form nitrite by reducing nitrate or by oxidizing ammonia.

These results again show that the tests for total residual chlorine have to be interpreted with caution unless conditions are well defined.

SECTION XII

FATE OF CHLORINE ADDED TO SECONDARY EFFLUENT

Mill trials have shown that the amount of chlorine required to provide bactericidal activity in secondary effluents can be reduced by converting molecular chlorine to hypochlorous acid and/or sodium hypochlorite (Table 49). This is probably due to the greater reactivity of molecular chlorine. However, effects of pH on other reactants may be involved. For example, when molecular chlorine is used, effluent pH is lowered by the hydrolysis products HCl and HOCl. This tends to repress the ionization of lignosulfonates and perhaps make them more reactive.

Results from the mill studies also indicated that the reaction products of chlorine and effluent may vary qualitatively with the form of chlorine used. On July 21, 1972 (Table VI, Appendix) 5.0 ppm chlorine with NaOH addition was more bactericidal than 17.5 ppm chlorine without it, even though the latter provided higher concentrations of total residual chlorine.

It is possible that a chlorine-lignosulfonate complex is formed, when Cl_2 is used, which releases active chlorine under acidic test conditions but not at the neutral pH of chlorinated effluent.

Another possible reason for the lack of correlation between total residual chlorine and bactericidal activity would be the oxidation of ammonia to nitrite by molecular chlorine. This would lead to a false positive test for total residual chlorine. Laboratory tests (Table 55) showed that 0.1 ppm NO_2^- in effluent would be sufficient for this.

Further studies on chlorine reactions were made with sodium hypochlorite, as this form of chlorine is used in the modified mill treatment system.

ANALYTICAL METHODS

Amperometric titrations based on procedures described by Rebertus[12] were used to analyze for various species of chlorine. The methods are based on the following characteristics of chlorine compounds:

a. Free chlorine (hypochlorous acid, HOCl) can be titrated with standard phenylarsenoxide solution at pH 7. Addition of potassium iodide (KI) is not required.

b. Monochloramine (NH_2Cl), but not dichloramine, reacts quantitatively with KI at pH 7. The liberated iodine can be titrated with phenylarsenoxide.

c. Dichloramine ($NHCl_2$) at pH 4 oxidizes KI to I_2 which can be titrated.

By making successive titrations on the same sample, with addition of appropriate reagents, the various forms of chlorine can be distinguished. However, in this study with secondary effluents, separate titrations were made to increase sensitivity and to minimize reaction times for each chlorine species. With this technique an initial titration made at pH 4 with KI present measures total residual chlorine which includes HOCl, NH_2Cl, $NHCl_2$ and other forms of combined chlorine. Dichloramine cannot be identified as such. The following equation summarizes the relationships.

$$\begin{array}{c}\text{Total Residual}\\ \text{Chlorine}\end{array} - HOCl - NH_2Cl = NHCl_2 + \begin{array}{c}\text{Other Forms of}\\ \text{Comb. Chlorine}\end{array}$$

The test conditions, addition of NaOCl to pH 7 effluent, would favor the formation of NH_2Cl over $NHCl_2$. At this pH, equilibrium reactions also would result in predominance of the monochloramine. If no NH_2Cl was detected in a sample it was assumed that $NHCl_2$ also was absent and that the nature of combined chlorine would remain undefined.

Analyses were made with a Metrohm Herisau E436 Potentiograph and E436D automatic titrator (Brinkmann). A platinum foil working electrode and calomel reference electrode were used with a polarizing voltage of 0.1 V. This and other instrument settings are given in Table 64. Sensitivity of the methods for the various forms of chlorine was 0.04 ppm.

Table 64. INSTRUMENT SETTINGS FOR CHLORINE DETERMINATIONS

Control marking[a]	Dial setting
Stop	0
Calibr. pH	0
Epol.	0.1
µA/50 mV	5
Ipol.	0
0 0 (Titration)	10
Temp. °C.	22
mV x 100 comp.	0
pH/ mV/ 250 mm	50
dE/dt	Epol.

[a] For Metrohm Herisau E436 Potenticgraph.

FORMATION AND STABILITY OF VARIOUS FORMS OF CHLORINE

Sodium hypochlorite was added to secondary effluent to provide initial chlorine concentrations of 6 to 12 ppm. Chlorine analyses were made at intervals from 5 minutes to 4 hours. Positive tests for total residual chlorine were obtained for all samples. Residuals persisted for approximately 15 minutes when the initial chlorine concentration was 6 ppm (Table 65). At higher application rates, residuals were found after 1 hour but not after 4 hours reaction time.

Table 65. RECOVERY OF CHLORINE ADDED TO SECONDARY EFFLUENT

Chlorine added, ppm	Reaction time, minutes	Chlorine recovered, ppm		
		Free Cl (HOCl)	Monochloramine	Total residual
6	0 to 5	< 0.04	< 0.04	0.31
	15	< 0.04	< 0.04	0.08
	30	< 0.04	< 0.04	< 0.04
	60	< 0.04	< 0.04	< 0.04
	240	< 0.04	< 0.04	< 0.04
8	0 to 5	< 0.04	< 0.04	1.24
	15	< 0.04	< 0.04	0.52
	30	< 0.04	< 0.04	0.46
	60	< 0.04	< 0.04	0.12
	240	< 0.04	< 0.04	< 0.04
10	0 to 5	< 0.04	0.06	1.23
	15	< 0.04	< 0.04	0.93
	30	< 0.04	< 0.04	0.58
	60	< 0.04	< 0.04	0.27
	240	< 0.04	< 0.04	< 0.04
12	0 to 5	< 0.04	0.16	1.66
	15	< 0.04	< 0.04	1.45
	30	< 0.04	< 0.04	1.03
	60	< 0.04	< 0.04	0.91
	240	< 0.04	< 0.04	< 0.04

Free chlorine (HOCl) was not found in any of the samples. Monochloramine was detected in samples receiving 10 and 12 ppm chlorine but not in those with less chlorine. The chloramines were not stable. They could not be detected after 15 minutes.

Chloramine reactions were studied further. First it was found that when sodium hypochlorite was added to an aqueous solution of NH_4^+ at pH 7 the only active form of chlorine detected was monochloramine. In other tests monochloramine was added to secondary effluent to provide an initial concentration of 10 ppm chlorine. Titrations made after 10 minutes reaction time showed no trace of the chloramine.

The results show that both free chlorine and monochloramine react rapidly with secondary effluent to produce a form of combined chlorine which is more stable than chloramines, but gradually reacts completely with effluent. It appears very unlikely that chlorination under the conditions described would produce chloramine residuals in secondary effluent.

DURATION OF BACTERICIDAL ACTIVITY

The same source of effluent and chlorinating solution used in the preceeding tests were utilized in microbiological studies. Effluent was treated to contain the same initial chlorine concentrations as before. The effects of chlorine on microorganisms were evaluated with the Oxygen Uptake Test, Motility Test and by enumerating coliforms and other bacteria. For the last two tests residual chlorine was inactivated with sodium thiosulfate. Results are summarized in Table 66.

Effect on Oxygen Uptake

The rate of oxygen uptake by secondary effluent was inhibited by all concentrations of chlorine tested. Although no total residual chlorine

Table 66. EFFECT OF TOTAL RESIDUAL CHLORINE ON MICROORGANISMS

Analysis and Cl addition	Reaction time							
	Start	10 min	30 min	1 hr	2 hr	3 hr	4 hr	24 hrs
Total resid. Cl[a]								
Cl added, ppm								
0	0	0	0	0	0	0	0	0
6	--[b]	0.20	$<$ 0.04	$<$ 0.04	$<$ 0.04	$<$ 0.04	$<$ 0.04	$<$ 0.04
8	--	0.90	0.46	0.12	--	--	$<$ 0.04	$<$ 0.04
10	--	1.10	0.58	0.27	--	--	$<$ 0.04	$<$ 0.04
12	--	1.60	1.00	0.91	--	--	$<$ 0.04	$<$ 0.04
Colif/100 ml X 10^5								
Cl added, ppm								
0	80.0	50.0	2.0	3.0	--	--	--	70.0
6	80.0	$<$ 0.0001	$<$ 0.0001	$<$ 0.0001	--	--	--	0.17
8	80.0	$<$ 0.0001	$<$ 0.0001	$<$ 0.0001	--	--	--	0.008
10	80.0	$<$ 0.0001	$<$ 0.0001	$<$ 0.0001	--	--	--	1.0
12	80.0	$<$ 0.0001	$<$ 0.0001	$<$ 0.0001	--	--	--	$<$ 0.0001
Total bact/100 ml X 10^7								
Cl added, ppm								
0	280.0	280.0	330.0	340.0	--	--	--	94.0
6	280.0	36.0	4.4	1.4	--	--	--	8.8
8	280.0	4.8	0.22	--	--	--	--	0.15
10	280.0	13.0	--	--	--	--	--	0.06
12	280.0	1.4	--	--	--	--	--	0.0002
Motile spir./field								
Cl added, ppm								
0	1.0-10	1.0-10	1.0-10	1.0-10	1.0-10	1.0-10	1.0-10	1.0-10
6	1.0-10	1.0-10	0	0	0	0	0	0.01-0.10
8	1.0-10	0	0	0	0	0	0	0
10	1.0-10	0	0	0	0	0	0	0
12	1.0-10	0	0	0	0	0	0	0
Effluent D.O.								
Cl added, ppm								
0	8.4	7.6	6.8	6.2	4.8	3.2	2.1	0.2
6	8.6	8.2	7.8	7.4	6.9	6.5	5.7	0.2
8	8.6	8.4	8.1	8.0	7.7	7.5	7.3	4.6
10	8.4	8.2	8.0	7.8	7.6	7.5	7.4	6.2
12	8.8	8.6	8.3	8.2	7.9	7.9	7.7	7.3

[a] Estimated from data in Table 65.

[b] -- Not determined.

could be detected after 4 hours, the inhibition continued for 24 hours. In all cases there was a linear decrease in D.O. concentration with time (Figure 45). These results suggest that portions of the total bacterial population were killed rapidly by chlorine and that the D.O. uptake reflected the activity of the remaining viable bacteria.

Effect on Reproduction

Within 10 minutes coliform concentrations were reduced to less than 100/100 ml by all concentrations of chlorine. Apparently all coliforms were killed by 12 ppm as none could be detected after 24 hours. For at least 20 hours of this incubation period there was no total residual chlorine which could act as an inhibitor. At lower levels of chlorine, coliforms grew during the 24 hour period but final concentrations were only small percentages of those present before chlorination. This may have been due to growth of a very small number of survivors which utilized nutrients leached from killed bacteria. Results were similar with the total bacterial population but complete kill was not attained.

Effect on Motility

Results from the Motility Test correlated with those from MF analyses for coliforms. Both procedures showed that 6 ppm Cl was effective. The Motility Test can be made more demanding by reducing the contact time from 30 minutes to 10 minutes. As shown in Table 66, with the shorter time, 8 ppm chlorine was required to stop motility.

The effect of time on the bactericidal activity of chlorine residuals was evaluated further using the following procedures:

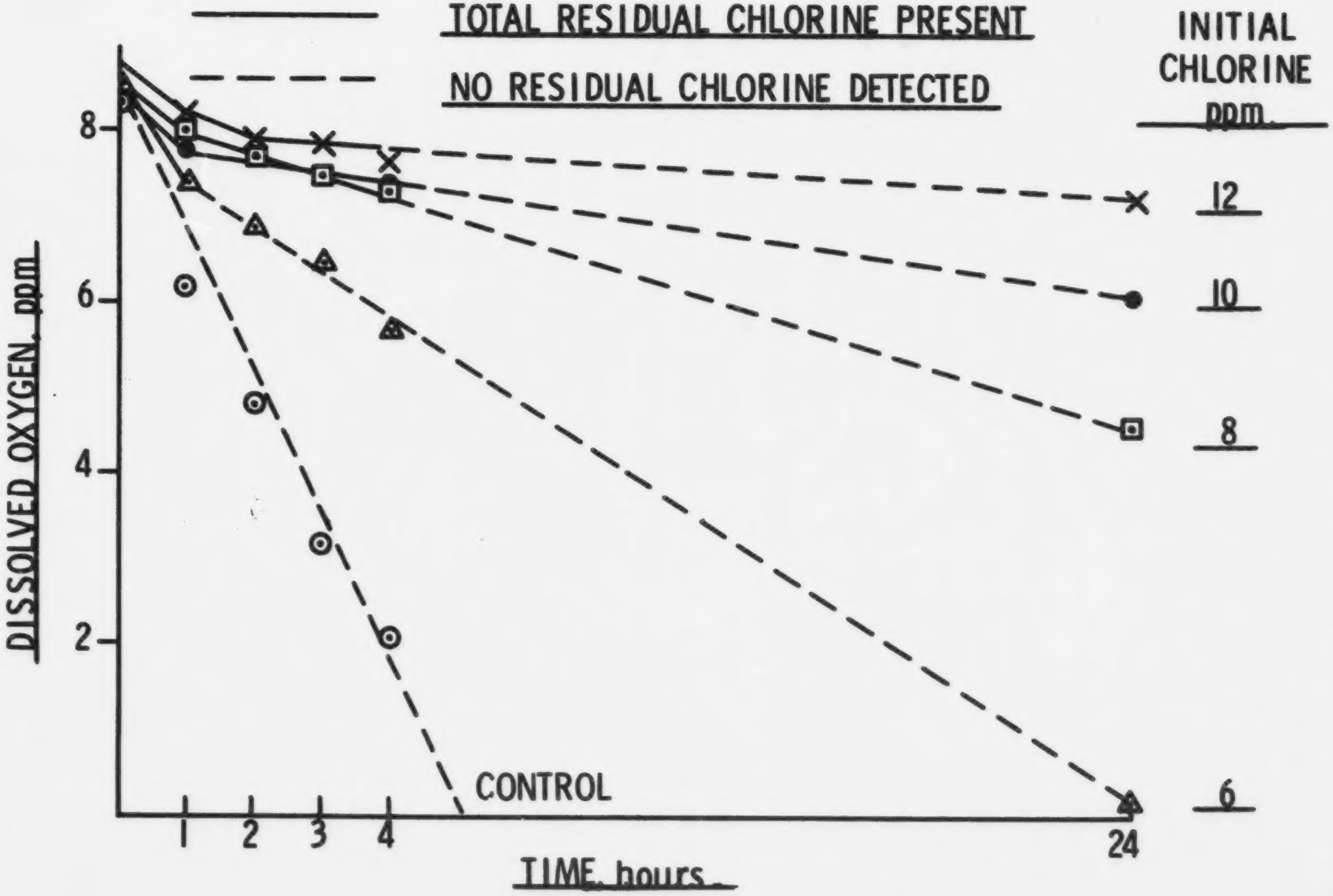

Figure 45. Effect of total residual chlorine on oxygen uptake by secondary effluent.

a. To obtain a concentrated suspension of bacteria, a sample of secondary effluent was centrifuged for 5 minutes at 9750 xg. The supernatant was decanted and the sedimented bacterial cells were resuspended in 1 percent of the original effluent volume.

b. The supernatant from step (a) was the source of cell-free effluent.

c. Sodium hypochlorite was added to cell-free effluent to provide an initial chlorine concentration of 10 ppm. At intervals ranging from 30 seconds to 2 hours, two 100 ml samples were taken. One sample was analyzed for total residual chlorine. The other sample was inoculated with 1 ml of the bacterial suspension.

d. Uniform, 30 minute reaction times were allowed for the inoculated samples. Sodium thiosulfate was then added to inactivate any residual chlorine. After recovery periods of approximately 30 minutes, the concentrations of motile spirilla were determined by microscopic observation.

In summary the procedure provided for different reaction times between chlorine and effluent, then uniform 30 minute reaction times between chlorine residuals and bacteria.

Results showed that the chlorine residuals which were present in effluent after reaction times of 30 seconds to 1 hour completely stopped bacterial motility or greatly reduced it (Table 67). After a reaction time of 2 hours, residual chlorine was still present in the effluent, however the residual did not inhibit bacterial motility. This lack of bactericidal activity could have been due either to a qualitative change in the nature of the residual or to a quantitative decrease to a concentration below the toxic threshold.

Table 67. STABILITY AND BACTERICIDAL ACTIVITY OF TOTAL RESIDUAL CHLORINE

Reaction time[a]	Total residual chlorine, ppm	Motile spirilla per field after 30 minutes[b]
0	0	1-10
30 Seconds	4.0	0
5 Minutes	3.7	0
30 Minutes	3.4	0.01-0.10
1 Hour	2.4	0
2 Hours	1.5	1-10

[a] Reaction time between chlorine and cell-free effluent.

[b] After 30 minutes in the presence of the total resid. chlor. concentrations shown in the middle column.

When considered along with the results from previous tests, these findings bring up some interesting questions concerning the nature of chlorine residuals. Amperometric titrations (Table 65) showed that the active forms of chlorine, hypochlorous acid and the chloramines, do not persist for more than 15 minutes in effluent treated with 6 to 12 ppm of chlorine. Yet, the total chlorine residual which remains exhibits considerable activity for a relatively long time. This has relevance to the toxicity of residuals in receiving waters and possibly to the development of new types of germicides.

SECTION XIII

FISH TOXICITY OF CHLORINATED EFFLUENTS

STATIC LABORATORY TESTS

Procedure

Fish were kept in a 10 gallon aquarium and fed daily until 4 days before testing. Then they were transferred to wide mouth, 2 l assay jars and feeding was discontinued. The jars contained 1-2 inch layers of coarse aquarium gravel and carborundum air stones for aeration when required. Test materials were added to measured water volumes in the jars and the contents were mixed by gentle swirling. Test procedures were based on those described in Standard Methods.[3] Unless noted otherwise the duration of the tests was 96 hours.

Tests with Gambusia

Preliminary tests with fresh water minnows (*Gambusia sp.*), showed that chlorinated effluent was not toxic in concentrations up to 10 percent (v/v), the highest level tested. For these experiments sodium hypochlorite was added to effluent to provide an initial chlorine concentration of 10 ppm. After a reaction time of 15 minutes, aliquots of chlorinated effluent were added to the assay jars which contained 4 fish each.

Tests with Guppies (Lebistes reticulatus)

Aerated Effluent -- Gambusia became unavailable so further testing was done with guppies. In the first experiment effluent was treated to obtain an initial chlorine concentration of 10 ppm. After aging for two hours, the chlorinated effluent was aerated mechanically and transferred to assay jars. Higher concentrations of chlorinated effluent were used than in the preceeding experiment, to obtain a TL 50 value. This is the concentration of a toxic material which permits survival of 50 percent of the fish.[3] Samples were aerated continuously with compressed breathing air.

Results (Table 68) showed that TL 50 values were in the range of 40 to 63 percent for both the chlorinated effluent and for unchlorinated controls. Other data indicated that the chlorinated waste was slightly more toxic. At concentrations of 10, 16, 25 and 40 percent, one out of five fish died in chlorinated effluent but not in the controls.

The chlorinated effluent used in the test had received a bactericidal concentration of chlorine, as shown by a decrease in coliform concentrations from 160 million per 100 ml to less than 100 per 100 ml (Table 68).

Non-Aerated Effluent -- A similar experiment was made with no aeration. The toxicity of both chlorinated and unchlorinated effluent was less than when the samples were aerated. Only 1 out of 5 fish was killed in 63 percent treated or untreated effluent (Table 69). In aerated samples all fish were killed by this concentration (Table 68). There was an indication that the chlorinated effluent was slightly more toxic as 1 fish died in 50 percent and 2 fish died in 40 percent chlorinated effluent. There was no mortality in the controls at these effluent concentrations.

The chlorinated effluent used in the test had received a bactericidal concentration of chlorine, as shown by a decrease in coliform concentrations from 10 million per 100 ml to less than 100 per 100 ml (Table 69).

Table 68. EFFECT OF CHLORINATION ON THE TOXICITY OF SECONDARY EFFLUENT TOWARD GUPPIES IN AERATED SAMPLES

Treatment of effluent	Eff conc in jars, % (v/v)	Number of survivors out of 5 after:				Coliforms/100 ml X 10^5 after:	
		1 Day	2 Days	3 Days	4 Days	Start[a]	1 Day
Water control	0	5	5	5	5	0	40
None	2.0	5	5	5	5	30	--[b]
	10.0	5	5	5	5	160	40
	16.0	5	5	5	5	260	--
	25.0	5	5	5	5	400	90
	40.0	5	5	5	5	640	--
	63.0	3	0	0	0	1000	360
	100.0	-	-	-	-	1600	--
Chlorinated and aged for 2 hours	2.0	5	5	5	5	<0.001	--
	10.0	5	5	5	5	<0.001	210
	16.0	5	5	4	4	0.001	--
	25.0	5	4	4	4	0.002	520
	40.0	5	4	4	4	0.002	--
	63.0	0	0	0	0	0.005	120
	100.0	-	-	-	-	0.006	--

[a] Calculated from initial concentration in 100% effluent.

[b] -- Not determined.

Table 69. EFFECT OF CHLORINATION ON THE TOXICITY OF SECONDARY EFFLUENT TOWARD GUPPIES IN NON-AERATED SAMPLES

Treatment of effluent	Eff conc in jars, % (v/v)	Number of survivors out of 5 after:			Coliforms/100 ml X 10^5 after:	
		1 Day	2 Days	4 Days	Start[a]	1 Day
Water control	0	5	5	5	0.001	0.001
None	32	5	5	5	32	33
	50	5	5	5	50	37
	63	5	5	4	63	51
	100	--[b]	--	--	100	64
Chlorinated and aged for 2 hours	10	5	5	5	0.001	2.2
	16	5	5	5	0.001	--
	25	5	5	5	0.001	--
	32	5	5	5	0.001	1.3
	40	5	5	3	0.001	0.8
	50	5	5	4	0.001	0.3
	63	5	5	4	0.001	0.8
	100	--	--	--	0.001	0.001

[a] Calculated from initial concentration in 100% effluent.

b -- Not determined.

Effect of Aeration on Toxicity -- The cause of the greater toxicity of the aerated samples was not determined. Possibly it was due to differences in the effluent. The tests with aerated samples were made on November 15, 1971 and non-aerated samples were evaluated one week later with different waste.

Another possibility is related to the toxicity of NH_4OH. Secondary effluent from Lebanon contains approximately 140 ppm ammonia nitrogen (NH_3N).[13] The amount which exists as NH_3 or NH_4OH depends on the pH of the effluent. It is the unionized form of NH_3N which, in low concentration, is toxic to fish. Ellis[13] estimated that 2.5 ppm NH_3 was lethal to goldfish. Aeration may purge CO_2, produced by microorganisms, from solution and increase effluent pH and consequently the concentration of NH_4OH. pH measurements were not made during these tests; however, in other experiments, removal of dissolved gasses by reduced pressure increased effluent pH from 6.9 to 7.4. These values will be used to illustrate the point.

From the disassociation constant of NH_4OH,[10]

$$Kb = \frac{(NH_4^+)(OH^-)}{NH_4OH} = 1.8 \times 10^5 \text{ @ } 25^\circ \text{ C},$$

the ratio of $NH_4^+ : NH_4OH$ can be calculated for different effluent pHs with the following equation:

$$\frac{(NH_4^+)}{(NH_4OH)} = \frac{Kb}{(OH^-)} = \frac{1.8 \times 10^{-5}}{\text{antilog-}(14\text{-pH})}$$

From this, the percent of total NH_3N which is unionized can be calculated. If the amount of NH_3N in effluent is known, the concentration of NH_3 can be calculated, as can the concentration of effluent required to supply a toxic level of NH_3. Results of such calculations (Table 70),

Table 70. RELATIONSHIP BETWEEN EFFLUENT pH AND CONCENTRATIONS OF NH_4^+ AND NH_4OH

Effluent			$\frac{(NH_4^+)}{(NH_4OH)}$[a]	NH_4OH, as NH_3[b]		Eff conc, % for 2.5 ppm NH_3
pH	pOH	(OH^-)		%	ppm	
6.0	8.0	1.00×10^{-8}	1800	0.056	0.10	100
6.1	7.9	1.26×10^{-8}	1430	0.070	0.12	100
6.2	7.8	1.58×10^{-8}	1140	0.088	0.15	100
6.3	7.7	2.00×10^{-8}	900	0.111	0.19	100
6.4	7.6	2.52×10^{-8}	710	0.141	0.24	100
6.5	7.5	3.16×10^{-8}	570	0.175	0.30	100
6.6	7.4	3.98×10^{-8}	450	0.222	0.38	100
6.7	7.3	5.00×10^{-8}	360	0.277	0.47	100
6.8	7.2	6.30×10^{-8}	290	0.344	0.58	100
6.9	7.1	7.93×10^{-8}	230	0.433	0.74	100
7.0	7.0	1.00×10^{-7}	180	0.552	0.94	100
7.1	6.9	1.26×10^{-7}	143	0.694	1.18	100
7.2	6.8	1.58×10^{-7}	114	0.870	1.48	100
7.3	6.7	2.00×10^{-7}	90	1.100	1.87	100
7.4	6.6	2.52×10^{-7}	71	1.390	2.36	100
7.5	6.5	3.16×10^{-7}	57	1.720	2.92	86
7.6	6.4	3.98×10^{-7}	45	2.170	3.69	68
7.7	6.3	5.00×10^{-7}	36	2.700	4.59	54
7.8	6.2	6.30×10^{-7}	29	3.330	5.66	44
7.9	6.1	7.93×10^{-7}	23	4.170	7.09	35
8.0	6.0	1.00×10^{-6}	18	5.260	8.94	28
8.5	5.5	3.16×10^{-6}	6	14.900	25.30	10
9.0	5.0	1.00×10^{-5}	2	35.700	60.70	4

[a] $\frac{(NH_4^+)}{(NH_4OH)} = \frac{Kb}{(OH^-)} = \frac{1.8 \times 10^{-5}}{\text{antilog--(14--pH)}}$

[b] Total ammonia concentration in effluent is approximately 170 ppm.

based on an average NH_3 value for Lebanon effluent of 170 ppm[13] and a toxicity level of 2.5 ppm[14], show that an effluent concentration of 86 percent would be toxic at pH 7.5. An average of 215 ppm NH_3 was found in Lebanon effluent during a 28 day period in 1969.[13] At this concentration, 40 percent effluent would be toxic at pH 7.5; 49 percent at pH 7.4, and undiluted effluent would be toxic at pH 7.1. Actual toxicity levels will vary according to a number of factors including the species of fish used. However these considerations show that toxicity due to ammonia has to be considered when testing high concentrations of Lebanon effluent.

Toxicity of Chlorine and Chloramine -- Sodium hypochlorite was added to Santiam River water and to Santiam River water supplemented with 100 ppm NH_3. Amperometric titrations showed that chlorine was converted to monochloramine in the latter case. Initial chlorine concentrations were 10 ppm. The solutions were adjusted to pH 7 and various amounts were added to assay jars containing guppies in Santiam River water. The samples were not aerated. Monochloramine proved to be more toxic than hypochlorous acid (Table 71). TL50 values for the two species were approximately 0.40 ppm and 0.80 ppm (as Cl), respectively. A concentration of 1.8 ppm of either compound killed some fish within 6 hours.

Table 71. TOXICITY OF HYPOCHLOROUS ACID AND MONOCHLORAMINE TO GUPPIES

Chlorine additions		Cl in assay jars, ppm	Number of fish surviving after			
Solution	Sol'n conc in jars, %		1 Day	2 Days	3 Days	4 Days
None	0	0	4	4	4	4
HOCl in water pH 7.0 10 ppm Cl	1.8	0.18	4	4	4	4
	3.2	0.32	4	4	4	4
	5.6	0.56	4	4	4	4
	10.0	1.00	3	2	1	1
	18.0	1.80	0	0	0	0
	32.0	3.20	0	0	0	0
NH_2 Cl in 100 ppm NH_4 Cl pH 7.0 10 ppm Cl	1.8	0.18	4	4	4	4
	3.2	0.32	4	4	4	4
	5.6	0.56	4	3	2	2
	10.0	1.00	1	1	0	0
	18.0	1.80	0	0	0	0
	32.0	3.20	0	0	0	0

Comparison of Chlorine Toxicity in Water and in Effluent -- In this series of tests river water and effluent were treated to contain 10 ppm initial chlorine. An expression which indicates the effect of effluent on the toxicity of chlorine compounds can be obtained by comparing the percents of chlorinated materials required to kill half of the test fish within 4 days, TL50 values.

$$ETI = \frac{TL50\ Cw}{TL50\ CE} \times 100$$

In the expression above, ETI is the effluent toxicity index, Cw is chlorinated water and CE is chlorinated effluent.

When HOCl was added to water the ETI was less than 13:

$$ETI = \frac{8}{>63} \times 100 = <13$$

This indicates that chlorine added to effluent is less than 13 percent as toxic as chlorine added to water. Similar calculations for monochloramine give an ETI value of less than 7.

The values are conservative as TL50s were not reached with 63 percent effluent (Table 69), the highest concentration tested. As discussed earlier, with higher levels of effluent, factors other than chlorine residuals have to be considered in relation to fish toxicity, e.g., unionized ammonia.

Inactivation of Chlorine Toxicity by Effluent

Toxic amounts of NaOCl were added to assay jars which contained fish in river water, with and without additives. Samples were not aerated. Interpretation of results from this experiment is difficult because all of the fish died in the river water control within 4 days and the addition of NH_4Cl seemed to have a beneficial effect (Table 72). The following results were obtained after 1 day of testing, when half of the controls were alive.

Table 72. INACTIVATION OF CHLORINE TOXICITY BY EFFLUENT AND CHLORINATED EFFLUENT

Jar contents				Number of fish surviving after			
Cl, ppm	NH_3N, ppm	Effluent, %					
		No chlor	Chlorin[a]	1 Day	2 Days	3 Days	4 Days
0	0	0	0	2	1	0	0
0	100	0	0	4	4	3	2
2.0	0	0	0	0	0	0	0
2.0	0	5	0	0	0	0	0
2.0	0	50	0	4	4	4	4
2.0	0	0	1	0	0	0	0
2.0	0	0	5	0	0	0	0
2.0	0	0	50	1	1	0	0
2.0	100	0	0	0	0	0	0
2.0	100	5	0	0	0	0	0
2.0	100	50	0	4	3	3	2
2.0	100	0	1	0	0	0	0
2.0	100	0	5	0	0	0	0
2.0	100	0	50	1	1	1	0

[a] Treated with NaOCl to contain 10 ppm Cl and aged for 30 minutes.

Two ppm chlorine, in the presence and absence of NH_4^+, was lethal to guppies.

Chlorine toxicity was completely inactivated by 50 percent unchlorinated effluent and somewhat reduced by 50 percent chlorinated effluent. Lower concentrations of either material were ineffective.

The greater effectiveness of unchlorinated effluent may have been due to the presence of low concentrations of reducing agents such as sulfite which would react with chlorine before it would effect the fish. In the chlorinated waste these compounds would have been oxidized and reactions between chlorine and other effluent constituents were probably too slow to protect the fish.

The laboratory tests showed that chlorinated effluents have a low degree of acute toxicity for fish. They also indicate that toxic chlorinated phenolic compounds are not formed by chlorinating secondary effluent. The procedures were limited in one important area. They measured the toxicity of chlorine residuals for only a brief time. Normally, residuals do not persist for longer than 2 hours and in the static test are not replenished. Under actual conditions, if residuals did persist, fish would be exposed to low concentrations of them continuously. This situation was evaluated in field studies which are described in the following section.

CONTINUOUS FLOW FIELD TESTS

Methods and Equipment

Apparatus was constructed to carry out 5 necessary procedures for continuous toxicity tests: chlorination; aging of chlorinated effluent; dilution of aged, chlorinated effluent; evaluation of fish toxicity; and evaluation of bactericidal activity.

Chlorination -- Toxicity tests were started before a reliable mill chlorination procedure was developed. For the first two trials secondary effluent was treated with commercial sodium hypochlorite to obtain initial chlorine concentrations of 10 ppm. A photograph of the equipment used to do this, and to accomplish subsequent procedures, is shown in Figure 46. A schematic is presented in Figure 47. Effluent and a stock solution of sodium hypochlorite, at appropriate flow rates, were mixed in a funnel which imparted a swirling action. Further mixing occurred from gravity flow to the mix box. Details of this and other procedures are given in the section APPARATUS AND METHODS.

When full scale continuous chlorination was in effect mill chlorinated effluent was pumped to the mix box and the above procedure was not used.

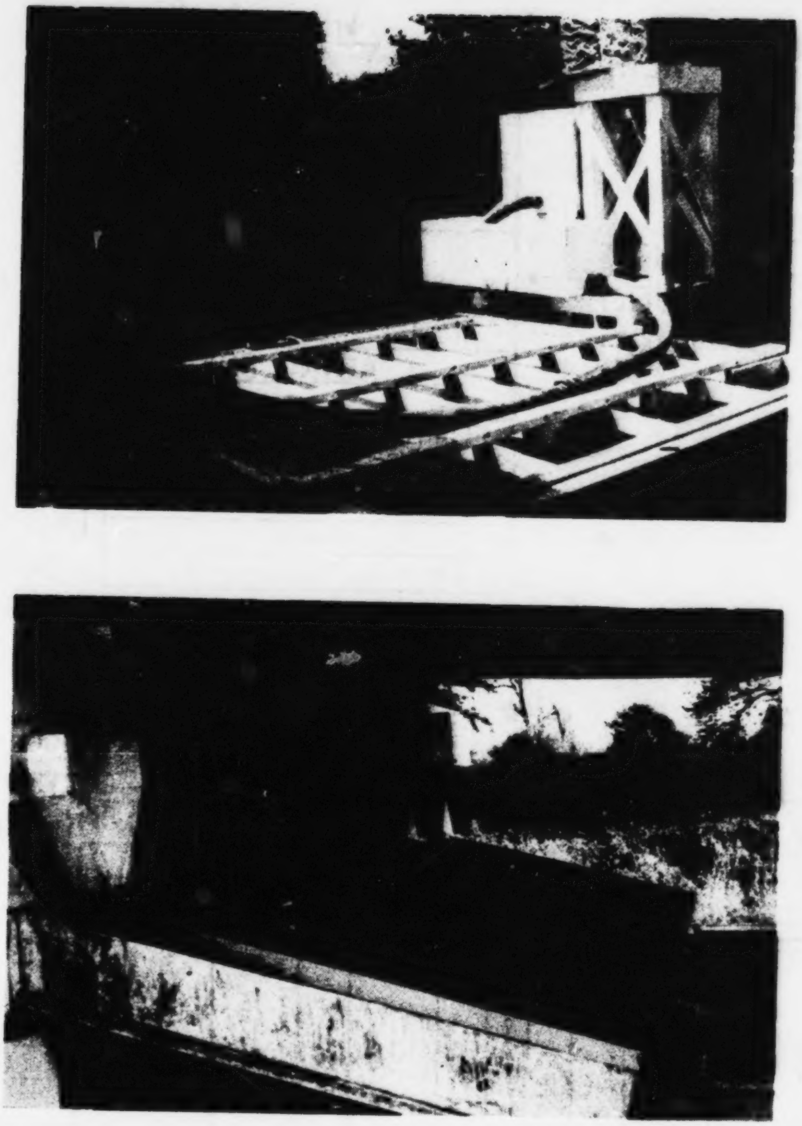

Figure 46. Apparatus for evaluating toxicity of chlorinated effluents.

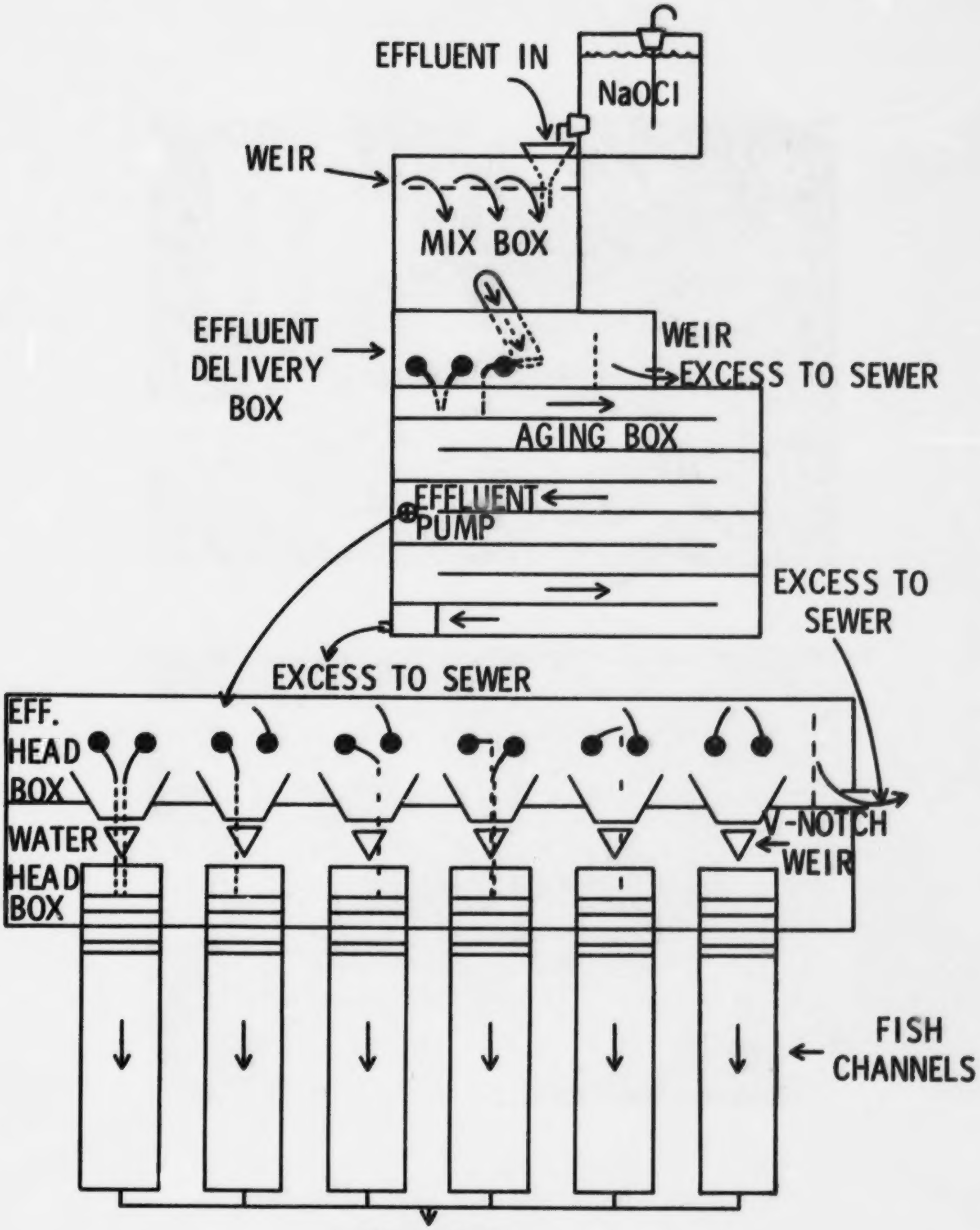
EFFLUENT IN
NaOCl
WEIR
MIX BOX
EFFLUENT DELIVERY BOX
WEIR
EXCESS TO SEWER
AGING BOX
EFFLUENT PUMP
EXCESS TO SEWER
EXCESS TO SEWER
EFF. HEAD BOX
WATER HEAD BOX
V-NOTCH WEIR
FISH CHANNELS
TO SEWER

Figure 47. Schematic of apparatus for evaluating toxicity of chlorinated effluents.

Reaction products of chlorine and effluent should be similar or the same for the two chlorination methods. In the modified mill procedure Cl_2 is converted to NaOCl and/or HOCl.

Aging of Chlorinated Effluent -- An aging box was constructed in the form of a labyrinth (Figures 46 and 47). Each of the eight channels had a capacity of 454 l (120 gal.) which was equivalent to a retention time of 20 minutes in these experiments. Since the channels were 2.44 m (8 ft) long, each 0.305 m (1 ft) represented a retention time of 2.5 minutes. The aging box was calibrated on this basis. Any retention time up to 160 minutes could be obtained by placing the effluent pump inlet at the appropriate location in the aging box.

Dilution of Aged Chlorinated Effluent -- Chlorinated effluent was pumped from the aging box to the effluent headbox (Figures 46 and 47) at a rate slightly exceeding that required for the next stage. This provided a constant head. Effluent was transferred to a riffle section leading to the fish channels by means of adjustable flow delivery tubes. River water from the water headbox also flowed to the riffle area where it mixed with the effluent. Desired water flow rates were obtained by adjusting V-notch weirs.

Evaluation of Fish Toxicity -- The procedures described in Standard Methods[3] were followed. The liquid flow rate to each of the fish channels, which were 6.1 m (20 ft) long, was maintained at 0.631/sec (10 gal./min). This provided a velocity of 2.0 cm/sec (4 ft/min). For the first two experiments 10 steelhead trout were used per channel. For the next 5 trials sockeye salmon were used at the rate of 20 per channel.

Evaluation of Bactericidal Activity -- Coliforms in chlorinated effluent were enumerated by the MF method. In addition, the Oxygen Uptake test was used to evaluate the effect of chlorination on the total bacterial population. Normally, unchlorinated secondary effluent takes up dissolved oxygen at the rate of 2 ppm/hr (Figure 22). As shown earlier (Table 35), inhibition of this rate by 64 percent or more indicates that coliforms have been reduced to acceptable levels. The aging box provided the means for making this a very rapid field test. By taking D.O. measurements at two points a known distance apart, consequently a known time interval apart in the calibrated channels, the rate of oxygen uptake by chlorinated effluent can be calculated as can the percent inhibition of the normal rate.

Results

Summary -- Seven toxicity tests were made. Since they differed in one or more respects they will be discussed individually. However, a summary of the more important data for all of the trials is given in Table 73. The results showed that secondary effluent which was chlorinated sufficiently to kill coliforms was not toxic to sockeye salmon, providing the effluent was aged for two hours and diluted to final concentrations of 20 percent or less. This is approximately 20 times the maximum effluent concentration estimated for the South Santiam River.

Experiment 1 -- Within 1 day all of the test fish, steelhead trout, were killed by 50 percent chlorinated effluent and by 67 percent unchlorinated effluent (Table X, Appendix). A 50 percent concentration of the latter showed no toxicity during the 1 day test. In this trial sodium hypochlorite was added to provide an initial chlorine concentration of 10 ppm. However the effluent line to the mix box became partially plugged. For a time effluent flowed at about half of the normal rate while chlorine addition rates were normal. This increased the initial chlorine concentration to approximately 20 ppm which was double the desired concentration.

Table 73. CONTINUOUS FLOW FISH TOXICITY TESTS. SUMMARY OF DATA

Measurement	Test number 1	2	3	4	5	6	7
Starting date (1972)	April 3	April 10	July 10	Aug. 7	Aug. 14	Aug. 20	Aug. 20
Duration of test (days)	1.0	4.0	2.0	4.0	4.0	4.0	4.0
Eff conc tested, %							
Control	50, 67	50	20	None	None	None	None
Chlorinated	50	5-40	5-20	5-20	5-20	5-20	5-20
Fish species (no./channel[a])	SH (10)	SH (10)	SS (20)	SS (20)	SS (20)	SS (20)	SS (20)
Initial chlor conc in eff, ppm	10.0	10.0	4.1-6.9	5.4-6.4	4.4-6.3	3.9-5.4	4.5-5.0
Safe cond no toxic effects							
Control eff							
Eff conc, %	50	--[b]	20	--	--	--	--
Time, days	1.0	--	2.0	--	--	--	--
Chlorinated eff							
Eff conc, %	--	5	20	20	10	20	20
Time, days	--	4	4	4	4	4	4
Toxic conditions							
Control eff							
Eff conc, %	67	50	Not	--	--	--	--
Time, days	1	1	Present	--	--	--	--
Fish killed, %	100	100	0	--	--	--	--
Estimated TL50, %	58	<50	>20	--	--	--	--
Chlorinated eff							
Eff conc, %	50	10	Not	Not	20	Not	Not
Time, days	1	4	Present	Present	3	Present	Present
Fish killed, %	100	30	0	0	5	0	0
Estimated TL50, %	<50	12	>20	>20	>20	>20	>20
Bactericidal activity of Cl							
Coliform reduction, %	99.997	99.999	--	99.996	>99.999	99.999	99.999
Inh of O_2 uptake, %	88	96	--	90	65	89	88
Cl resid in eff headbox, ppm	0	4.3	0	0-0.7	0-0.8	0-0.6	--

[a] SH = Steelhead Trout; SS = Sockeye Salmon.

[b] -- Not determined.

Experiment 2 -- Conditions were the same as for the previous test -- small scale chlorination to obtain an initial concentration of 10 ppm Cl; a 1 hour aging time for chlorinated effluent and the use of 10 steelhead trout per channel. In this trial 60 percent of the fish were killed in 20 percent chlorinated effluent within 1 day and by the end of the test there was significant toxicity at the 10 percent level (Table XI, Appendix). Unlike previous results, 50 percent unchlorinated effluent was quite toxic. It killed 70 percent of the fish within 1 day and all of them within two days.

The relatively high degree of toxicity of the wastes may have been partially due to the high pH of river water and its mixtures with effluent. In the case of unchlorinated effluent, toxicity would be related to the concentration of unionized ammonia. From the information in Table 70 and a pH value of 7.6 for 50 percent effluent in this experiment it can be calculated that the unionized ammonia concentration would be 1.8 ppm. In the previous experiment 50 percent effluent at pH 7.2 would have an NH_3 concentration of only 0.74 ppm.

High pH values also would increase the concentration and stability of chlorine residuals in effluent. Evidence for this was the essentially complete coliform kill, the almost complete inhibition of oxygen uptake and the presence of chlorine residuals in the effluent headbox and in the fish channels. Total residual chlorine was consistently detected in channels containing 20 percent or more of chlorinated effluent. In 2 out of 3 tests it was found in 10 percent effluent and on one occasion residuals were apparent in the channel containing 5 percent effluent.

Experiment 3 -- For experiments 3 through 7 effluent from full scale mill chlorination was used and the aging time was increased to 2 hours.

Results from experiment 3 (Table XII, Appendix) showed that aging was necessary to detoxify chlorinated effluent. Twenty percent unaged waste killed 25 percent of the fish within 3.5 hours and all of them within a day. After aging for 2 hours no toxicity was found during the 2 day test period. Equipment failure caused a premature end to this trial

Experiment 4 -- No toxicity was found for 20 percent chlorinated effluent, the highest concentration tested, during the 4 day test period (Table XIII, Appendix). Chlorination was effective as shown by the consistent, high degree of inhibition of oxygen uptake and reduction of coliforms to less than 100 per 100 ml. Initial chlorine concentrations in this and the succeeding trials were considerably less than in the first two experiments where the small scale chlorinator was used to provide chlorine levels of 10 ppm. The treatment used in this series of tests was 113 Kg/day (250#/day) of chlorine and 82 Kg/day (180 #/day) of NaOH, a combination which proved effective in numerous tests (Table VIII, Appendix).

Experiments 5-7 -- Results from these 3 experiments (Tables XIII-XV, Appendix) were essentially the same as described for experiment 4. Chlorination was effective in killing coliforms and 20 percent chlorinated effluent had no adverse effects on sockeye salmon during 4 day test periods.

SECTION XIV

EVALUATION OF MISCELLANEOUS BACTERIOCIDES

COMPARISON OF CHLORINE DIOXIDE AND SODIUM HYPOCHLORITE

Stock solutions of chlorine dioxide (ClO_2) and sodium hypochlorite ($NaOCl$) were prepared to contain 1000 ppm active chlorine. Aliquots were added to secondary effluent to provide initial chlorine concentrations of 2-10 ppm. After 30 minute contact times portions of the samples were analyzed for total residual chlorine. Other portions were treated with sodium thiosulfate to inactivate any residual chlorine then examined microscopically to determine the effect of treatment on bacterial motility.

It was found that ClO_2 at every concentration tested produced total chlorine residuals. The concentrations after 30 minutes were from 25 to 43 percent of added chlorine (Table 74). There was however no effect on bacterial motility. In contrast, 6 ppm chlorine, added as $NaOCl$, did not produce a 30 minute chlorine residual however it stopped motility completely.

The reason for the lack of correlation between positive tests for chlorine residuals and the absence of bactericidal activity with ClO_2 was not determined. Chlorine dioxide is a strong oxidizing agent. It is possible that it oxidized some of the NH_3 in effluent to NO_2^- which in turn would give a false positive test for total residual chlorine.

Table 74. COMPARISON OF CHLORINE DIOXIDE AND SODIUM HYPOCHLORITE

Cl added as	Initial Cl conc, ppm	30 Min Cl resid		Motile spirilla per field @ 30 min
		ppm	% of ini	
Control	0	0		1-10
Chlorine dioxide	2	0.5	25	1-10
	4	1.4	35	1-10
	6	2.1	35	1-10
	8	3.3	41	1-10
	10	4.3	43	1-10
Sodium hypochlorite	2	0	0	1-10
	4	0	0	0.1-1.0
	6	0	0	0
	8	0.9	11	0
	10	0.5	5	0

Formaldehyde and Paraformaldehyde

A Formalin solution containing 37 percent formaldehyde, 15 percent methanol and 48 percent water was diluted in water to obtain stock solutions. Aliquots of these were added to secondary effluent. After 30 minutes, samples were examined microscopically to determine effects on bacterial motility. Results from these screening tests showed that effective concentrations were between 10 and 100 ppm. Controls containing 10,000 ppm methanol had no adverse effect on motility. Similar tests showed that 100 to 1000 ppm paraformaldehyde were required to stop motility.

Hydrogen Peroxide

Commercial, 20 percent hydrogen peroxide (H_2O_2) was diluted and evaluated as described for the preceeding experiments. A concentration of 2000 ppm H_2O_2 stopped bacterial motility in 15 but not in 5 minutes; a concentration of 1000 ppm was ineffective during a 30 minute test period.

Ozone (O_3)

A Welsbach Model T-23 Laboratory Ozonator[15] was set up at the mill site and operated on tank oxygen. The amount of ozone produced was measured by sparging output gasses into 2 percent potassium iodide (KI) contained in two traps connected in series. Iodine produced by the oxidation of KI was measured by acidic titration with 0.025 N $Na_2S_2O_3$ to a colorless starch end point. Ozone production were calculated using the following formula:

$$\frac{O_3\ \text{Prod,}}{\text{mg/hr}} = \frac{\text{ml}}{\text{Thio}} \times \frac{\text{N of}}{\text{Thio}} \times 24 \times \frac{\text{Trap Vol}}{\text{Samp Vol}} \times \frac{60}{\text{Time, min}}$$

To ozonate secondary effluent the sparger was placed in the vertical section of a 3.8 cm (1.5 in.) O.D. rubber hose carrying the waste. From measured ozone production rates and effluent flow rates initial ozone concentrations were calculated. Reactions between effluent and ozone were monitored by smelling the continuously treated waste. Since ozone at concentrations of 0.1 ppm or less can be easily detected by odor,[14] the absence of its aroma was considered to be evidence that most if not all of the applied ozone had reacted with effluent.

In a typical experiment ozone output was found to be 525 mg/hr. Effluent flow through the hose was adjusted to 1140 L/hr (5 gal./min). The ozone outlet with the sparger was then positioned in the effluent stream. Under these conditions the initial ozone concentration was 0.46 ppm. A sample of the ozonated effluent was taken, then the effluent flow rate was reduced without changing the rate of ozone production. Using this method initial ozone concentrations of 0.46 to 4.6 ppm were obtained. In this range no excess ozone could be detected by its odor. No residual ozone was present. Analyses made on the samples after 30 minute reaction times showed no significant effect on bacterial motility and no reduction in concentrations of bacteria (Table 75).

Table 75. EFFECT OF OZONE ON BACTERIA

Ini O_3 conc, ppm	Ozone res, ppm	Motile spirilla/field[a]	Bacteria/100 ml[a]	
			Total x 10^5	Colif x 10^4
0	0	1-10	88	36
0.46	0	0.1-1.0	123	36
92	0	0.1-1.0	145	42
2.30	0	0.1-1.0	173	28
4.60	0	0.1-1.0	185	45

[a] After 30 minute reaction times.

At the highest application rate tested, 21 ppm, not all of the ozone reacted with effluent. This may have been related to the velocity of oxygen-ozone mixtures, rather than to saturation of reactive sites. Gas flow at the high ozone production rate was 2.0 l/min compared to 0.4 l/min at lower production rates. The high rate of ozone addition did not stop bacterial motility.

SECTION XV

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SECTION XVI

GLOSSARY

Anaerobic - Complete absence of oxygen.

Bactericidal Activity - Killing of bacteria.

Biological Chlorine Demand - The concentration of chlorine, in ppm, required to reduce coliform bacteria to acceptable levels within a specified time.

BOD - Biochemical Oxygen Demand.

Caustic - Commercial, technical grade sodium hydroxide (NaOH). Concentration of NaOH is usually between 40 and 50 percent (w/w).

Colicidal Activity - Killing of coliform bacteria.

Coliforms - In this report the term coliforms means total coliform bacteria. These are aerobic or facultative anaerobic, gram-negative, non-spore forming, rod-shaped bacteria which ferment lactose at 35° C. within 24 to 48 hours, depending on the assay method.

EPA Unit - A pilot secondary treatment unit operated at the Lebanon mill by personnel of the Environmental Protection Agency.

Five (5) Minute Residual - Total residual chlorine found after a contact time of 5 minutes.

Inactivation (of chlorine) - Elimination of the bactericidal activity of chlorine residuals.

MF Coliforms - Coliform bacteria enumerated by the membrane filter method of analysis.

MT Coliforms - Coliform bacteria enumerated by the presumptive, lactose fermentation test using multiple tubes (5 in this study) for each sample size tested.

Orzan® - Trade name of lignosulfonate by-products manufactured by Crown Zellerbach Corporation. AL and GL grades contain ammonia lignosulfonates and KSL and LS contain sodium lignosulfonates.

Primary Treatment - A process for removing fibers and other particles from wastes.

Secondary Treatment - A process for reducing the BOD of a waste.

Total Bacteria - All bacteria which produce colonies on a standard plate count agar which is incubated aerobically.

Water Leg - A column of water flowing through a pipe which has a section of relatively small diameter. The increased water velocity in the constricted section produces a partial vacuum which can be tapped to operate an evaporator.

SECTION XVI

APPENDICES

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Table I. CHARACTERISTICS OF SECONDARY COMPOSITE EFFLUENT DURING PARALLEL OPERATION

Date	Time	pH	Temp °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml		Colif, % of total
						Total X 10^7	Colif X 10^5	
(1971)								
Sept. 14	--[a]	6.8	--	--	72	47	22	0.47
22	--	6.7	24.0	--	87	380	31	0.08
23	--	6.9	24.0	--	93	98	48	0.49
24	--	--	--	--	105	19	53	2.8
28	--	7.0	22.5	--	102	490	33	0.07
29	--	7.2	--	--	98	150	49	0.33
Monthly mean		6.9	23.5	--	93	197	39	0.71
S.D. from monthly mean		0.2	0.9	--	12	193	12	1.04
S.D. from project mean		0.3	0.9	--	19	215	232	1.65
Dec. 13	1635	7.2	13.0	--	96	230	15	0.25
14	1425	7.2	13.0	--	96	210	18	0.23
15	1040	7.5	13.5	--	131	16	29	1.1
23	0955	7.0	14.0	--	119	35	104	5.7
27	1545	7.3	12.5	--	100	9	54	6.2
30	1340	6.6	12.0	--	138	290	16	0.19
31	0955	6.6	--	--	122	--	18	--
31	0840	6.6	--	--	122	--	25	--
Monthly mean		7.0	13.0	--	116	132	35	2.3
S.D. from monthly mean		0.4	0.7	--	16	125	26	2.9
S.D. from project mean		0.4	11.5	--	19	209	233	2.9

[a] -- Not determined.

Table I (continued). CHARACTERISTICS OF SECONDARY COMPOSITE EFFLUENT DURING PARALLEL OPERATION

Date	Time	Ph	Temp °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml		Colif, % of total
						Total X 10^7	Colif X 10^5	
(1972)								
Feb. 1	--[a]	6.9	14.5	--	163	160	210	1.3
2	--	6.8	14.0	--	192	170	180	1.1
3	--	6.8	14.5	--	190	63	18	0.29
8	1425	6.8	18.0	--	162	150	140	0.93
10	1155	6.8	18.5	--	177	410	10	0.02
11	1525	6.6	18.7	--	177	130	44	0.34
12	1130	6.8	18.7	--	182	280	110	0.39
Monthly mean		6.8	16.7	--	178	195	102	0.62
S.D. from monthly mean		0.1	2.2	--	11	115	80	0.48
S.D. from project mean		0.4	7.7	--	78	150	202	1.4
March 13	1525	6.8	20.9	--	121	76	140	1.8
13	1815	6.8	20.9	--	121	58	90	1.6
14	0840	6.8	20.4	--	121	81	130	1.6
14	1140	6.9	21.3	--	121	--	230	--
14	1340	6.8	21.4	--	121	--	210	--
14	1425	6.8	21.6	--	121	99	290	2.9
14	1515	6.9	21.4	--	121	42	270	6.4
14	1605	6.9	21.4	--	121	43	190	4.4
15	0935	7.0	21.5	--	105	200	140	0.70
15	1230	7.2	22.7	--	105	110	130	1.2
15	1610	7.2	23.1	--	105	210	100	0.48
16	0905	7.2	23.0	--	99	150	200	1.3
16	1650	7.2	24.5	--	99	140	190	1.4
17	0840	7.2	22.5	--	99	150	160	1.1
18	1143	7.3	21.8	--	86	140	90	0.60
22	1605	7.0	21.3	--	95	70	400	5.7
24	0855	6.9	20.8	--	105	93	440	4.7
24	1145	6.9	20.0	--	105	50	340	6.8
24	1730	7.0	20.1	--	105	70	470	6.7
Monthly mean		7.0	21.6	--	109	105	222	2.9
S.D. from monthly mean		0.2	1.1	--	11	52	117	2.3
S.D. from project mean		0.2	2.2	--	12	192	121	2.6

[a] - Not determined.

Table I (continued). CHARACTERISTICS OF SECONDARY COMPOSITE EFFLUENT DURING PARALLEL OPERATION

Date	Time	pH	Temp °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml		Colif, % of total
						Total X 10^7	Colif X 10^5	
(1972)								
April 4	--[a]	--	--	--	109	150	1300	8.7
12	--	7.4	17.1	--	91	130	90	0.69
13	--	7.2	--	--	111	31	210	6.8
Monthly mean		7.3	17.1	--	104	104	533	5.4
S.D. from monthly mean		0.1	--	--	11	64	667	4.2
S.D. from project mean		0.3	--	--	11	230	751	6.0
May 18	1030	6.5	--	--	132	680	810	1.2
18	1200	6.6	--	--	132	460	710	1.5
18	1430	6.8	--	--	132	510	1000	2.0
25	1415	7.3	--	--	137	--	550	--
Monthly mean		6.8	--	--	133	550	768	1.6
S.D. from monthly mean		0.4	--	--	3	115	188	0.41
S.D. from project mean		--	--	--	32	346	625	0.55
June 8	1330	6.8	29.0	--	98	470	330	0.70
9	1045	7.0	28.5	--	98	170	330	1.9
12	1650	6.6	25.3	--	91	700	110	0.16
13	1050	6.6	26.0	--	91	360	80	0.22
13	1440	6.6	28.4	--	91	460	120	0.26
14	1435	6.6	26.0	--	83	410	140	0.34
15	1400	6.2	26.8	--	89	410	160	0.39
20	1405	5.6	28.0	--	88	460	140	0.30
27	1440	7.2	29.0	--	92	--	360	--
28	1310	6.8	29.0	--	98	1000	380	0.38
29	1520	7.2	--	--	86	--	310	--
30	1230	7.0	31.0	--	86	--	24	--
Monthly mean		6.7	27.9	--	91	493	207	0.52
S.D. from monthly mean		0.4	1.7	--	5	234	125	0.54
S.D. from project mean		--	4.9	--	17	323	133	1.5

[a] -- Not determined.

Table I (continued). CHARACTERISTICS OF SECONDARY COMPOSITE EFFLUENT DURING PARALLEL OPERATION

Date	Time	pH	Temp °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml		Colif, % of total
						Total X 10^7	Colif X 10^5	
(1972)								
July 5	1145	5.6	29.0	--[a]	93	440	150	0.34
6	0100	5.6	29.0	--	89	500	52	0.10
6	1445	5.4	28.0	--	89	460	50	0.11
7	1245	6.0	28.0	--	89	360	16	0.04
7	2015	6.2	28.0	--	89	--	26	--
8	0800	6.5	27.1	--	93	--	24	--
8	1540	6.6	26.6	--	93	--	22	--
8	2100	6.6	26.6	--	93	--	22	--
10	1600	6.4	--	--	84	--	700	--
11	1050	5.7	27.3	--	84	--	90	--
11	1210	5.7	27.3	--	84	--	132	--
18	1139	6.9	31.0	--	74	--	72	--
19	1030	--	30.2	--	91	--	28	--
21	1130	6.6	31.6	4.3	106	--	3	--
25	0730	6.9	27.7	3.0	105	--	7	--
27	1315	7.2	--	--	75	--	340	--
31	1515	6.9	29.9	--	84	--	590	--
Monthly mean		6.3	28.5	3.6	89	440	137	0.15
S.D. from monthly mean		0.6	1.6	0.9	8	59	209	0.13
S.D. from project mean		1.0	5.4	0.9	19	190	240	2.0
Aug. 3	1303	6.7	29.3	--	79	220	560	2.5
8	1327	6.7	32.4	4.4	94	--	14	--
11	0740	6.7	28.4	--	81	--	7	--
16	2025	7.1	27.1	--	78	--	3	--
18	0540	6.9	25.4	--	87	540	4	0.01
24	0635	7.4	28.1	--	73	--	1200	--
29	1140	7.3	30.8	--	93	695	495	0.71
30	1610	7.1	29.9	--	95	850	480	0.56
31	1028	7.3	28.7	--	91	515	250	0.49
Monthly mean		7.0	28.9	4.4	86	564	335	0.85
S.D. from monthly mean		0.3	2.0	--	8	235	400	0.96
S.D. from project mean		0.3	6.1	--	23	391	410	1.5

[a] -- Not determined.

Table I (continued). CHARACTERISTICS OF SECONDARY COMPOSITE EFFLUENT DURING PARALLEL OPERATION

						Bacteria/100 ml		
Date	Time	pH	Temp °C	SO_3, ppm	BOD, ppm	Total X 10^7	Colif X 10^5	Colif, % of total
(1972)								
Sept. 19	1603	7.0	24.0	4.4	157	94	120	1.3
20	0845	6.1	23.0	3.7	122	87	120	1.4
21	1230	6.4	23.0	3.0	112	100	190	1.9
22	0920	7.0	22.0	--[a]	112	91	40	0.44
26	0912	7.0	19.0	3.9	95	280	730	2.6
Monthly mean		6.7	22.2	3.8	120	130	240	1.5
S.D. from monthly mean		0.4	1.9	0.6	23	84	279	0.80
S.D. from project mean		0.6	2.4	0.6	28	191	279	0.88
Oct. 5	1015	6.9	23.0	--	114	220	400	1.8
6	1700	7.0	22.0	--	114	410	110	0.27
7	1304	7.0	24.0	4.9	93	360	110	0.31
9	1333	7.0	22.8	3.4	99	130	520	4.0
10	1700	7.2	22.0	3.1	99	360	520	1.4
11	1104	7.0	21.1	3.0	104	310	260	0.84
13	1832	6.9	22.7	3.0	97	350	290	0.83
16	1400	6.9	23.4	3.9	106	240	770	3.2
17	1102	7.1	23.4	3.3	106	120	1000	8.3
18	0938	7.1	22.0	3.1	78	91	1500	16.5
19	1500	7.0	22.0	2.8	81	210	440	2.1
24	1500	7.0	19.4	3.6	95	320	240	0.75
26	1300	7.0	21.5	3.3	80	600	370	0.62
31	1600	7.0	18.2	3.4	93	640	230	0.36
Monthly mean		7.0	22.0	3.4	97	312	483	2.9
S.D. from monthly mean		0.1	1.6	0.6	12	164	382	4.3
S.D. from project mean		0.1	2.2	0.6	15	166	451	4.6
Nov. 6	1025	6.8	20.0	4.3	92	320	210	0.66
8	1730	6.8	20.4	3.7	126	240	620	2.6
13	0945	6.9	21.6	3.2	130	1600	120	0.08
Monthly mean		6.8	20.7	3.7	116	720	317	1.1
S.D. from monthly mean		0.1	0.8	0.6	21	763	267	1.3
S.D. from project mean		0.3	3.6	0.6	24	931	278	1.6
Project mean		7.1	23.5	3.6	106	284	251	1.9
Project S.D.		0.5	4.9	0.6	25	256	291	2.2
No. of Analyses		104	93	22	107	82	107	82

[a] -- Not determined.

Table II. CHARACTERISTICS OF SECONDARY INFLUENT

Date	Time	pH	Temp. °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml		Colif., % of total
						Total X 10^7	Colif. X 10^5	
(1971)								
Sept. 4	1115	8.7	--[a]	--	240	70	4	0.06
Monthly mean		8.7	--	--	240	70	4	0.06
S.D. from monthly mean		--	--	--	--	--	--	--
S.D. from project mean		--	--	--	--	--	--	--
Dec. 13	1630	8.4	27.0	--	415	12	26	2.2
14	1950	8.4	26.0	--	415	16	34	1.5
15	1200	9.0	25.5	--	405	11	42	3.8
27	1520	8.3	--	--	410	2	4	2.0
30	1335	7.2	--	--	465	3	8	2.7
31	0730	9.5	--	--	395	--	4	--
Monthly mean		8.5	26.2	--	418	8.8	20	2.4
S.D. from monthly mean		0.8	0.8	--	24	6.1	17	0.9
S.D. from project mean		1.9	9.9	--	25	40	825	19
(1972)								
March 13	1530	5.4	30.5	--	410	7	160	23
13	1810	3.6	30.5	--	410	1	10	10
14	0810	3.8	30.8	--	440	3	70	23
14	1140	9.0	30.5	--	440	--	200	--
14	1340	6.0	30.7	--	440	--	68	--
14	1425	--	31.0	--	440	2	29	14
14	1515	--	31.0	--	440	7	60	8.6
14	1605	--	31.4	--	440	3	90	30
15	0915	9.3	31.8	--	440	4	160	40
15	1230	9.2	35.0	--	440	3	34	11
15	1610	--	35.5	--	440	2	2	1.0
16	1115	--	40.5	--	375	--	38	--
16	1655	--	35.5	--	375	1	9	9.0
17	0855	--	35.5	--	430	2	18	9.0
18	1143	4.0	30.5	--	430	0.2	7	35
22	1555	7.8	30.0	--	390	80	1370	17
24	0900	8.7	29.0	--	415	190	3300	17
24	1150	--	29.5	--	415	180	4000	22
24	1735	--	30.0	--	415	46	180	3.9
Monthly mean		6.7	32.1	--	422	33	516	17
S.D. from monthly mean		2.4	2.9	--	22	63	1150	11
S.D. from project mean		2.4	3.7	--	24	66	1180	11

[a] -- Not determined.

Table II(continued). CHARACTERISTICS OF SECONDARY INFLUENT

Date	Time	pH	Temp. °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml		Colif., % of total
						Total X 10^7	Colif. X 10^5	
(1972)								
Aug. 3	1300	--[a]	37.5	83	350	--	3100	--
8	1525	--	46.0	250	410	--	80	--
11	0730	--	40.0	234	450	--	29	--
16	2015	4.3	40.0	83	330	--	12	--
18	0530	--	41.0	--	460	23	520	23
24	0623	--	35.0	--	450	--	3300	--
28	1835	--	--	--	415	13	660	51
29	1205	5.5	41.0	--	415	35	1600	46
30	1700	--	32.0	--	350	3	52	17
31	0845	4.5	36.0	125	375	6	180	30
Monthly mean		4.8	38.7	155	400	16	953	33
S.D. from monthly mean		0.6	4.1	81	47	13	1280	15
S.D. from project mean		2.7	6.3	83	49	34	1290	22
Sept. 15	0945	4.2	35.0	--	500	120	1400	12
15	1235	8.8	37.0	--	500	12	1500	125
18	0810	9.0	35.0	--	400	3	12	4.0
19	1110	4.2	40.0	--	400	4	100	25
20	1115	3.2	40.0	269	400	0.9	34	38
21	0845	3.4	36.0	230	440	7	240	34
22	0830	7.2	32.0	58	440	3	330	110
26	0926	4.2	31.0	104	370	90	490	5.4
29	1145	4.2	33.0	--	365	50	50	1.0
Monthly mean		5.4	35.4	165	425	32	462	39
S.D. from monthly mean		2.3	3.0	100	50	45	582	46
S.D. from project mean		2.8	3.5	104	52	46	669	51

[a] -- Not determined.

Table II(continued). CHARACTERISTICS OF SECONDARY INFLUENT

Date	Time	pH	Temp. °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml Total X 10^7	Bacteria/100 ml Colif. X 10^5	Colif., % of total
(1972)								
April 12	--[a]	8.5	34.0	--	350	0.2	1	5.0
13	--	4.0	--	--	310	0.3	0.1	0.3
Monthly mean		6.2	34.0	--	330	0.25	1	--
S.D. from monthly mean		3.2	--	--	28	0.07	--	--
S.D. from project mean		3.3	--	--	121	62	--	--
June 8	1325	--	39.5	--	440	29	0.02	0.001
9	1130	9.4	34.0	--	350	11	15	1.4
12	1655	--	31.0	--	345	2	23	12
13	1055	6.8	29.0	--	435	9	290	32
13	1445	6.9	29.0	--	435	10	60	6.0
14	1425	--	32.5	--	435	110	360	3.2
15	1350	--	36.3	--	385	8	300	38
20	1545	--	46.0	--	415	0.07	0.2	0.29
28	1325	9.1	43.0	--	315	41	1300	32
Monthly mean		8.0	35.6	--	395	24	261	14
S.D. from monthly mean		1.4	6.1	--	48	35	417	16
S.D. from project mean		2.1	6.3	--	51	40	684	17
July 8	1532	9.3	32.2	--	355	--	80	--
8	2035	--	31.0	--	355	--	440	--
18	1143	--	40.0	--	430	--	80	--
19	1320	--	--	--	455	--	3400	--
21	1500	--	39.0	--	425	--	180	--
25	0720	--	34.0	--	420	--	2100	--
27	1450	--	--	175	440	--	3700	--
31	1555	--	41.0	--	360	--	740	--
Monthly mean		9.3	36.2	175	405	--	1340	--
S.D. from monthly mean		--	4.3	--	41	--	1520	--
S.D. from project mean		--	4.8	--	42	--	1630	--

[a] -- Not determined.

Table II(continued). CHARACTERISTICS OF SECONDARY INFLUENT

Date	Time	pH	Temp. °C	SO_3, ppm	BOD, ppm	Bacteria/100 ml Total X 10^7	Colif. X 10^5	Colif., % of total
(1972)								
Oct. 3	1145	9.6	37.0	--[a]	360	--	3200	--
5	1045	4.3	32.5	269	310	4	44	11
6	0815	4.5	30.5	123	310	12	130	11
7	1342	10.0	34.0	71	365	53	750	14
9	0800	4.6	34.0	147	490	39	1200	31
10	1245	8.0	32.5	106	490	39	120	3.1
11	1130	8.2	31.0	78	445	22	200	9.1
13	1515	8.1	33.5	124	475	46	290	6.3
16	0905	7.4	33.0	88	400	63	2000	32
17	0825	7.7	34.0	74	400	300	11000	37
18	0825	8.4	33.0	83	415	200	4100	20
19	1430	6.9	35.0	109	425	15	200	13
21	1430	7.7	33.0	--	395	37	220	5.9
26	1230	3.2	31.0	154	355	0.5	15	30
31	1415	8.7	33.0	78	390	20	210	10
Monthly mean		7.2	33.1	116	402	61	1580	17
S.D. from monthly mean		2.0	1.6	54	57	85	2890	11
S.D. from project mean		2.1	2.0	60	58	86	3010	11
Nov. 6	1025	9.5	32.0	60	430	500	110	0.22
8	1620	7.1	35.0	138	480	7	190	27
13	1330	9.3	37.0	89	465	4	42	10
16	1037	6.9	35.0	235	555	290	22	0.08
21	1215	6.9	40.0	197	450	0.46	3	6.5
25	1540	6.9	32.0	108	560	480	5700	12
30	1015	6.9	33.5	322	525	980	44	0.04
Monthly mean		7.6	34.9	164	495	140	873	8.0
S.D. from monthly mean		1.2	2.9	93	52	414	2130	9.7
S.D. from project mean		1.4	3.0	96	103	472	2130	15
Project mean		6.9	34.2	142	413	44	773	19
S.D.		2.1	4.3	72	57	152	1630	22
No. of analyses		58	78	30	86	68	86	68

[a] -- Not determined.

Table III. CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Total	Coliforms	
1 10/6/72 Start 5:00 PM	3	7.2	30.5	0.15	--[b]	72×10^7	46×10^6	6.4
	4	7.3	30.5	0.15	--	28×10^8	54×10^6	1.9
	5	7.2	30.0	0.15	--	26×10^8	70×10^6	2.7
	6	1.9	29.0	0.15	--	17×10^2	<10	<0.6
	7	1.9	28.2	0.15	--	14×10^2	<10	<0.7
	8	7.4	26.0	0.15	--	43×10^2	<10	<0.2
	9	6.9	23.6	2.8	3.4	36×10^8	13×10^6	0.36
	10	6.9	23.6	3.4	3.4	49×10^8	13×10^6	0.27
	Mill sec.	6.9	25.0	--	3.4	41×10^8	11×10^6	0.27
1 10/7/73 0.9 Day	3	9.8	34.8	0.15	--	53×10^7	75×10^6	14
	7	2.0	29.8	0.15	--	--	--	--
	8	9.5	28.8	0.15	--	54×10^2	70	1.3
	9	6.2	26.0	2.4	3.1	27×10^8	60×10^4	0.02
	10	6.5	30.6	2.0	2.9	32×10^8	80×10^5	0.25
	Mill sec.	7.0	24.0	--	2.9	36×10^8	110×10^5	0.31
1 10/9/72 2.8 Days	3	6.7	32.7	0.10	--	49×10^8	$>100 \times 10^6$	>2.0
	4	6.6	31.5	0.35	--	33×10^8	$>100 \times 10^6$	>3.0
	5	6.5	30.7	0.10	--	37×10^8	$>100 \times 10^6$	>2.5
	6	2.5	29.7	0.70	--	32×10^8	$>100 \times 10^5$	>0.3
	7	2.4	28.8	0.80	--	29×10^5	62×10^4	21
	8	8.8	26.7	--	--	70×10^5	29×10^4	4.1
	9	6.8	25.7	1.8	2.4	28×10^7	50×10^4	0.18
	10	6.7	26.7	4.5	2.2	40×10^7	23×10^6	5.8
	Mill sec.	7.0	22.8	--	1.3	13×10^8	52×10^6	4.0

[a] See Figures 12 and 13.

[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Total	Coliforms	
1 10/10/72 4.0 Days	3	7.2	--[b]	--	--	15 X 10^8	24 X 10^7	16
	7	1.6	--	--	--	--	--	--
	8	6.5	--	--	--	30 X 10^3	22 X 10^2	7.3
	9	6.6	21.7	4.4	2.9	20 X 10^8	12 X 10^4	0.006
	10	6.5	22.7	0.4	2.9	22 X 10^8	68 X 10^6	3.0
	Mill sec.	7.2	22.0	---	3.1	36 X 10^8	52 X 10^6	1.5
1 10/11/72 4.8 Days	3	7.0	27.0	0.20	74	17 X 10^8	26 X 10^5	0.15
	7	1.8	21.9	--	--	--	--	--
	8	7.5	21.0	--	60	50 X 10^3	60 X 10^2	12
	9	6.6	22.0	4.5	2.8	28 X 10^8	70 X 10^3	0.002
	10	6.5	21.0	5.3	2.6	18 X 10^8	60 X 10^6	3.3
	Mill sec.	7.0	21.1	--	3.0	31 X 10^8	26 X 10^6	0.84
1 10/13/72 7.0 Days	3	6.3	29.4	0.10	--	15 X 10^8	10 X 10^7	6.7
	4	6.3	28.9	0.45	--	17 X 10^8	42 X 10^6	2.5
	5	6.3	28.8	0.10	--	21 X 10^8	10 X 10^7	4.8
	6	1.7	28.3	0.70	--	34 X 10^4	21 X 10^3	6.2
	7	1.7	27.7	0.80	--	6 X 10^6	420	0.007
	8	6.9	26.8	--	44	22 X 10^6	20 X 10^5	9.1
	9	6.6	21.8	2.2	3.3	50 X 10^8	63 X 10^4	0.013
	10	6.4	23.8	2.8	3.4	20 X 10^8	12 X 10^6	0.60
	Mill sec.	6.9	22.7	--	3.0	35 X 10^8	29 X 10^6	0.83

[a] See Figures 12 and 13.

[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Total	Coliforms	
1 10/16/72 10.0 Days	3	8.7	31.9	0.20	72	37 X 10^8	12 X 10^8	32
	4 Top	8.5	31.4	0.45	--[b]	36 X 10^8	11 X 10^8	31
	4 Bottom	--	--	--	--	117 X 10^9	60 X 10^9	51
	5 Top	8.1	30.8	0.20	--	29 X 10^8	9 X 10^8	3.1
	5 Bottom	--	--	--	--	73 X 10^9	14 X 10^9	19
	6	1.6	30.0	0.60	--	19 X 10^5	18 X 10^3	0.95
	7	1.6	29.3	0.70	--	35 X 10^4	600	0.17
	8	7.5	28.0	--	30	39 X 10^6	36 X 10^4	0.92
	9	6.6	22.6	2.6	3.2	130 X 10^6	19 X 10^5	1.50
	10	6.6	21.7	2.7	3.6	73 X 10^8	17 X 10^6	0.23
	Mill sec.	6.9	23.4	--	3.9	24 X 10^8	77 X 10^6	3.2
1 10/19/72 12.9 Days	3	6.5	31.0	0.05	75	40 X 10^8	14 X 10^7	3.5
	4 Top	6.4	27.7	0.05	--	33 X 10^8	11 X 10^7	3.3
	4 Bottom	--	--	--	--	64 X 10^9	56 X 10^8	8.8
	5 Top	6.4	26.8	0.10	--	29 X 10^8	12 X 10^7	4.1
	5 Bottom	--	--	--	--	44 X 10^9	62 X 10^8	14
	6	1.8	25.8	1.0	--	26 X 10^3	580	2.2
	7	1.7	24.0	1.2	--	35 X 10^2	200	5.7
	8	7.6	24.4	0.1	51	39 X 10^2	30	0.8
	9	6.6	22.0	2.2	2.5	88 X 10^8	34 X 10^4	0.004
	10	6.7	20.4	2.4	3.0	59 X 10^8	8 X 10^6	0.14
	Mill sec.	7.0	22.0	--	2.8	21 X 10^8	44 X 10^6	2.1

[a] See Figures 12 and 13.

[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Total	Coliforms	
1 10/24/72 17.9 Days	3	6.6	29.4	0.05	83	29×10^7	60×10^6	21
	4	7.0	28.7	0.05	--[b]	23×10^7	70×10^6	30
	5	7.2	27.9	0.20	--	60×10^7	80×10^6	13
	6	1.8	26.9	1.4	--	88×10^4	20×10^3	2.3
	7	2.0	26.0	1.6	--	37×10^5	21×10^4	5.7
	8	8.9	25.3	--	76	98×10^2	60	0.61
	9	7.2	21.8	5.4	2.4	17×10^8	31×10^3	0.002
	10	6.8	22.4	0.5	2.9	14×10^8	16×10^6	1.1
	Mill sec.	7.0	19.4	--	3.6	32×10^8	24×10^6	0.75
1 10/26/72 19.8 Days	3	8.6	31.8	1.5	138	50×10^6	6×10^6	12
	4	6.4	29.0	2.8	--	43×10^6	10×10^6	23
	5	5.0	27.4	3.1	--	56×10^6	10×10^6	18
	6	1.5	25.7	4.3	--	35×10^2	< 10	< 0.30
	7	1.5	23.7	4.1	--	62×10^4	< 10	< 0.002
	8	3.1	23.4	--	83	20×10^3	< 10	< 0.05
	9	7.3	21.8	8.4	2.4	94×10^8	24×10^3	0.0003
	10	7.4	21.7	2.1	2.2	52×10^8	14×10^6	0.27
	Mill sec.	7.0	21.5	--	3.3	60×10^8	37×10^6	0.62

[a] See Figures 12 and 13.
[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml Total	Bacteria/100 ml Coliforms	Colif., % of total
1 10/27/72 20.9 Days	3	6.4	32.0	0.30	--[b]	--	--	--
	4	6.3	32.0	0.15	--	--	--	--
	5	6.2	31.1	0.05	--	--	--	--
	7	1.4	30.0	1.6	--	--	--	--
	9	7.1	21.6	2.0	--	--	--	--
	10	7.0	21.6	2.6	--	--	--	--
1 10/30/72 23.9 Days	3	8.2	28.8	0.40	--	--	--	--
	4	8.4	28.2	0.15	--	--	--	--
	5	8.5	27.4	0.10	--	--	--	--
	7	1.9	26.0	2.2	--	--	--	--
	9	7.0	22.0	2.7	--	--	--	--
	10	6.8	22.2	2.3	--	--	--	--
1 10/31/72 24.9 Days	3	8.1	27.4	0.30	51	72×10^7	11×10^7	15
	4 Top	7.8	26.8	0.20	--	10×10^8	15×10^7	15
	4 Bottom	--	--	--	--	40×10^9	33×10^8	8.3
	5 Top	7.5	26.8	0.05	--	11×10^8	16×10^7	14
	5 Bottom	--	--	--	--	40×10^9	24×10^8	6.0
	6	1.7	24.9	0.80	--	24×10^4	9.0×10^2	0.38
	7	1.5	23.8	1.5	--	40×10^2	3.3×10^2	8.3
	8	7.4	23.6	--	88	49×10^4	18×10^3	3.7
	9	6.8	22.4	3.2	2.3	82×10^8	29×10^2	0.00004
	10	6.5	21.8	1.6	3.0	10×10^9	13×10^6	0.13
	Mill sec.	7.0	18.2	--	3.4	64×10^8	23×10^6	0.36

[a] See Figures 12 and 13.

[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Total	Coliforms	
1 11/2/72 26.9 Days	3	6.4	26.8	0.30	--[b]	--	--	--
	4	6.3	26.0	0.20	--	--	--	--
	5	6.3	25.7	0.05	--	--	--	--
	7	1.4	24.2	1.6	--	--	--	--
	9	6.7	20.1	1.8	--	--	--	--
	10	6.6	20.4	2.4	--	--	--	--
1 11/3/72 28.3 Days	3	7.7	26.0	0.35	--	--	--	--
	4	7.4	25.4	0.15	--	--	--	--
	5	7.5	24.6	0.05	--	--	--	--
	7	1.6	23.3	1.8	--	--	--	--
	9	6.7	20.6	1.6	--	--	--	--
	10	6.6	20.1	2.3	--	--	--	--
1 11/6/72 30.8 Days	3	9.9	27.2	0.85	56	29×10^8	20×10^7	6.9
	4 Top	9.5	24.8	0.25	--	23×10^8	26×10^7	11
	4 Bottom	--	--	--	--	27×10^9	32×10^8	12
	5 Top	9.3	23.0	0.10	--	66×10^7	14×10^7	21
	5 Bottom	--	--	--	--	38×10^9	17×10^8	4.5
	6	1.2	21.0	1.5	--	46×10^2	2.1×10^2	4.6
	7	1.2	19.8	2.0	--	43×10^2	<10	<0.23
	8	8.6	18.8	--	49	79×10^3	7×10^2	0.89
	9	6.6	19.6	0.5	2.5	62×10^8	14×10^2	0.00002
	10	6.6	20.5	2.8	2.6	87×10^8	12×10^6	0.14
	Mill sec.	6.8	20.0	--	4.3	32×10^8	21×10^6	0.66

[a] See Figures 12 and 13.
[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Total	Coliforms	
1 11/8/72 33.0 Days End	3	6.1	28.8	0.40	106	13×10^7	64×10^6	49
	4 Top	6.4	27.7	0.25	--[b]	54×10^8	12×10^8	22
	4 Bottom	--	--	--	--	55×10^9	13×10^9	24
	5 Top	7.3	27.0	0.10	--	59×10^8	10×10^7	1.7
	5 Bottom	--	--	--	--	29×10^9	10×10^9	34
	6	1.5	26.1	1.4	--	63×10^2	≤ 10	≤ 0.16
2 11/8/72 Start 5:00 PM	7	1.4	25.0	1.6	--	34×10^4	≤ 10	< 0.003
	8	9.6	24.2	--	83	69×10^5	69×10^3	1.0
	9	6.8	19.8	8.3	2.3	11×10^8	60×10^2	0.0005
	10	6.5	19.8	4.4	2.5	15×10^8	13×10^5	0.09
	Mill sec.	6.8	20.4	--	3.7	24×10^8	62×10^6	2.6
2 11/10/72 1.9 Days	3	7.4	23.7	0.60	--	--	--	--
	4	7.6	22.4	0.40	--	--	--	--
	5	7.7	22.2	0.25	--	--	--	--
	9	6.8	19.9	2.2	--	--	--	--
	10	7.2	20.6	7.9	--	--	--	--
2 11/13/72 4.8 Days	3	8.3	30.4	0.35	83	88×10^7	15×10^7	17
	4 Top	9.1	29.6	0.20	--	62×10^7	48×10^6	7.7
	4 Bottom	--	--	--	--	11×10^9	10×10^8	9.1
	5 Top	9.3	29.4	0.10	--	11×10^8	56×10^6	5.1
	5 Bottom	--	--	--	--	17×10^9	17×10^8	10
	9	6.6	21.8	1.2	4.4	24×10^9	23×10^6	0.10
	10	7.8	22.6	8.0	3.0	11×10^9	94×10^5	0.09
	Mill sec.	6.9	21.2	--	4.1	88×10^8	20×10^6	0.23

[a] See Figures 12 and 13.

[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Tctal	Coliforms	
2 11/14/72 5.9 Days	3	7.5	30.0	0.20	--[b]	--	--	--
	4	7.7	29.4	0.35	--	--	--	--
	5	8.1	28.7	0.10	--	--	--	--
	9	6.5	21.4	2.4	--	--	--	--
	10	7.3	21.6	8.1	--	--	--	--
2 11/15/72 6.9 Days	3	7.0	22.7	2.5	--	--	--	--
	4	8.5	20.6	3.0	--	--	--	--
	5	9.0	19.8	2.9	--	--	--	--
	9	6.6	22.4	2.2	--	--	--	--
	10	7.4	23.0	8.5	--	--	--	--
2 11/16/72 7.7 Days	3	6.1	27.2	0.30	214	35 X 10^8	11 X 10^6	0.31
	4 Top	6.1	25.0	1.2	--	55 X 10^8	56 X 10^6	1.0
	4 Bottom	--	--	--	--	39 X 10^9	10 X 10^8	2.6
	5 Top	6.1	20.0	1.2	--	28 X 10^8	28 X 10^7	10
	5 Bottom	--	--	--	--	37 X 10^9	51 X 10^8	14
	9	6.2	22.4	1.2	3.4	30 X 10^8	36 X 10^5	0.12
	10	7.2	24.0	7.4	2.9	68 X 10^8	13 X 10^5	0.02
	Mill sec.	7.1	20.8	--	2.4	20 X 10^8	60 X 10^5	0.30
2 11/18/72 9.8 Days	3	6.2	25.1	1.0	--	--	--	--
	4	6.2	24.7	0.70	--	--	--	--
	5	6.3	24.7	0.40	--	--	--	--
	9	6.4	22.4	1.7	--	--	--	--
	10	7.5	23.7	8.4	--	--	--	--
2 11/20/72 11.9 Days	3	6.5	26.2	0.70	--	--	--	--
	4	6.7	25.3	0.40	--	--	--	--
	5	6.7	25.0	0.05	--	--	--	--
	9			Out of service because of pump failure				
	10	7.4	23.6	7.8	--	--	--	--

[a] See Figures 12 and 13.

[b] -- Not determined.

Table III(continued). CHARACTERISTICS OF WASTES FROM MILL SECONDARY PONDS AND SMALL SCALE TREATMENT UNITS

Exp. # date elap. time	Sample point[a]	pH	Temp. °C	D.O., ppm	SO_3, ppm	Bacteria/100 ml		Colif., % of total
						Total	Coliforms	
2	3	6.4	37.0	3.4	169	46 X 10^6	27 X 10^6	59
11/21/72	4 Top	6.4	35.4	2.8	--[b]	33 X 10^6	10 X 10^6	30
12.8 Days	4 Bottom	--	--	--	--	43 X 10^8	22 X 10^7	5.1
Finish	5 Top	6.3	33.0	2.0	--	90 X 10^6	63 X 10^6	70
3	5 Bottom	--	--	--	--	94 X 10^8	15 X 10^8	16
11/21/72	10	7.2	23.8	7.7	2.8	16 X 10^9	40 X 10^4	0.003
Start 1:00 PM	Mill sec.	7.0	21.2	--	3.0	20 X 10^8	80 X 10^5	0.40
	3	6.0	27.0	0.70	85	86 X 10^7	17 X 10^7	20
	4 Top	6.0	23.4	1.8	--	54 X 10^9	60 X 10^8	11
3	4 Bottom	--	--	--	--	49 X 10^8	54 X 10^7	11
11/25/72	5 Top	6.0	26.2	1.6	--	69 X 10^8	64 X 10^7	9.3
4.0 Days	5 Bottom	--	--	--	--	12 X 10^9	47 X 10^7	3.9
	10	6.9	23.9	8.2	4.5	28 X 10^9	23 X 10^4	0.0008
	Pond 1	7.3	25.0	--	64	48 X 10^8	73 X 10^6	17
	Pond 2	7.0	18.4	--	4.7	43 X 10^7	18 X 10^7	3.8
	3	6.3	24.5	0.20	268	36 X 10^7	90 X 10^6	25
	4 Top	6.2	23.0	0.50	--	65 X 10^7	60 X 10^6	9.2
3	4 Bottom	--	--	--	--	11 X 10^9	53 X 10^8	48
11/30/72	5 Top	6.2	23.0	0.40	--	10 X 10^9	31 X 10^7	3.1
8.8 Days	5 Bottom	--	--	--	--	15 X 10^8	39 X 10^7	26
	10	6.4	20.0	8.2	2.9	29 X 10^9	36 X 10^5	0.12
	Mill sec.	7.0	19.8	--	7.9	97 X 10^8	92 X 10^6	0.95

[a] See Figures 12 and 13.

[b] -- Not determined.

Table IV. CHARACTERISTICS OF EFFLUENTS FROM PONDS 1 AND 2 DURING PARALLEL OPERATION

Date (1972)	pH		Temp., °C.		$SO_3^=$, ppm		BOD, ppm		Bacteria/100 ml Total X 10^3		Bacteria/100 ml Coliforms X 10^3		Coliforms, % of total	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Feb. 1	6.7	6.8	14.0	15.0	--[a]	--	166	161	260	110	290	250	1.1	2.3
2	6.6	6.8	13.0	15.0	--	--	166	161	110	150	120	120	1.1	0.80
3	6.7	6.8	14.0	15.0	--	--	183	201	40	28	33	8	0.82	0.29
8	6.7	6.8	17.5	18.1	--	--	175	148	92	190	130	90	1.4	0.47
10	6.9	6.8	18.0	18.0	--	--	136	157	390	330	15	2	0.04	0.01
11	6.6	6.6	18.4	19.3	--	--	181	172	180	20	150	20	0.83	1.0
12	6.7	6.7	18.6	19.3	--	--	181	172	400	220	240	60	0.60	0.21
Mean	6.7	6.8	16.2	17.1	--	--	170	167	210	160	140	79	0.64	0.73
S.D. (Interval)	0.1	0.1	2.4	2.0	--	--	16	17	144	120	100	87	0.44	0.77
S.D. (Proj.)	0.1	0.1	9.1	9.9	--	--	182	180	292	244	116	137	0.58	0.83
March 13	6.8	6.8	21.5	20.8	--	--	121	102	95	52	130	190	1.4	3.7
14	6.8	6.8	19.7	20.8	--	--	124	118	117	79	240	130	2.1	1.6
15	7.1	7.0	21.0	21.9	--	--	124	118	220	230	160	140	0.73	0.61
22	7.0	6.9	20.5	22.0	--	--	92	90	39	72	410	350	11	4.9
Mean	6.9	6.9	20.7	21.4	--	--	115	107	118	108	235	202	3.8	2.7
S.D. (Interval)	0.2	0.1	0.8	0.7	--	--	16	14	76	82	135	102	4.8	2.0
S.D. (Proj.)	0.3	0.2	4.3	5.5	--	--	132	122	396	288	135	186	5.7	2.8
June 28	7.0	6.7	28.0	29.5	--	--	75	98	1300	700	270	300	0.21	0.71
S.D. (Interval)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
S.D. (Proj.)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
July 5	5.4	5.7	28.5	29.5	--	--	--	--	630	75	190	21	0.30	0.28
(0100) 6	5.7	5.5	28.0	29.5	--	--	94	93	720	300	20	7	0.03	0.02
(1445) 6	5.3	5.4	27.8	28.0	--	--	94	93	360	360	80	20	0.14	0.06
7	5.8	6.1	26.5	29.0	--	--	81	97	430	280	25	6	0.06	0.02
(0800) 8	6.5	6.5	25.5	28.7	--	--	81	97	--	--	36	12	--	--
(1540) 8	6.6	6.6	25.1	28.0	--	--	81	97	--	--	29	15	--	--
(2100) 8	6.7	6.6	24.5	28.6	--	--	81	97	--	--	26	17	--	--

[a] -- Not determined.

Table IV (continued). CHARACTERISTICS OF EFFLUENTS FROM PONDS 1 AND 2 DURING PARALLEL OPERATION

Date (1972)	pH		Temp., °C.		NO_3^-, ppm		BOD, ppm		Bacteria/100 ml				Coliforms, % of total	
									Total X 10^7		Coliforms X 10^5			
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
July 11	5.6	5.8	26.0	28.6	--*	--	74	93	--	--	250	14	--	--
18	7.0	6.8	30.0	32.0	--	--	61	87	--	--	140	5	--	--
19	--	--	29.0	31.4	--	--	61	87	--	--	50	6	--	--
21	6.6	6.6	30.4	32.8	4.0	4.6	101	111	--	--	2	3	--	--
25	6.9	6.9	26.0	29.4	2.4	3.6	112	99	--	--	3	11	--	--
27	7.2	7.2	--	--	--	--	76	74	--	--	550	130	--	--
31	6.7	6.8	28.9	30.8	--	--	82	65	--	--	870	310	--	--
Mean	6.3	5.9	27.4	29.7	3.2	4.1	90	92	585	254	162	41	0.13	0.10
S.D. (Interval)	0.6	0.7	1.9	1.6	1.1	0.7	16	12	122	124	229	84	0.12	0.12
S.D. (Proj.)	0.8	0.7	3.8	4.1	1.3	0.8	86	94	195	171	254	266	1.2	1.1
Aug. 3	6.7	6.8	28.7	29.9	--	--	78	90	210	230	530	600	2.5	2.6
8	6.6	6.7	31.9	33.0	4.4	4.6	94	81	--	--	4	24	--	--
11	6.6	6.8	27.0	29.8	--	--	87	74	--	--	6	8	--	--
16	7.2	7.1	25.8	28.4	3.4	3.1	89	69	--	--	4	2	--	--
18	6.9	6.9	23.9	27.0	--	--	103	71	520	560	4	5	0.01	0.01
24	7.4	7.4	26.6	29.6	4.1	4.3	72	56	--	--	930	1400	--	--
29	7.3	7.3	29.8	31.7	--	--	94	93	800	590	270	720	0.34	1.2
30	7.1	7.1	28.8	31.0	--	--	94	93	500	1200	220	740	0.44	0.62
31	7.2	7.4	27.6	29.8	3.7	4.1	89	100	450	580	180	320	0.40	0.56
Mean	7.0	7.1	27.8	30.0	3.9	4.0	89	81	496	632	239	424	0.74	1.0
S.D. (Interval)	0.3	0.3	2.3	1.8	0.4	0.7	9	14	210	351	314	483	1.00	1.00
S.D. (Proj.)	0.4	0.5	4.4	4.5	0.6	0.7	93	85	216	468	317	550	1.1	0.98
Nov. 13	7.0	6.6	21.9	21.3	3.3	3.3	214	126	1900	1400	390	80	0.21	0.06
S.D. (Interval)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
S.D. (Proj.)	--	--	--	--	--	--	--	--	--	--	--	--	---	--
Proj. Mean	6.7	6.7	24.3	26.1	3.6	3.9	109	107	453	356	194	176	1.2	1.0
S.D.	0.5	0.5	5.2	--	0.7	0.6	116	112	443	365	232	326	2.3	1.3
No. of Analyses	35	35	35	35	7	7	35	35	22	22	36	36	22	22

* -- Not determined.

Table V. EFFECT OF MILL CHLORINATION ON BACTERIAL MOTILITY AND ON COLIFORM CONCENTRATIONS

Date (1972)	Cl added		Eff. pH	Motile spirilla per field	Colif./100 ml X 10^5	Colif. redn., %
	Kg/day (#/day)	ppm				
May 17	0	0	6.7	0.1-1	--[a]	--
	182 (400)	8.1	6.4	0.1-1	--	--
	227 (500)	9.9	6.3	0.1-1	--	--
	272 (600)	12.0	6.3	0.1-1	--	--
	318 (700)	14.0	6.3	0.1-1	---	--
	363 (800)	16.7	6.3	0.1-1	--	--
	408 (900)	19.1	6.2	0	--	--
	454 (1000)	21.2	6.2	0.01-0.1	--	--
May 18	0	0	6.6	0.1-1	710	0
	91 (200)	4.1	6.5	0.1-1	540	25
	136 (300)	6.2	6.5	0.1-1	640	10
	182 (400)	8.2	6.5	0.1-1	700	3
	227 (500)	10.5	6.4	0.1-1	640	10
	272 (600)	12.8	6.3	0.1-1	680	5
	318 (700)	14.9	6.2	0.1-1	770	0
	363 (800)	17.0	6.2	0.1-1	610	18
	408 (900)	19.2	6.1	0.1-1	930	0
	454 (1000)	21.2	6.1	0.1-1	730	0
May 19	0	0	7.4	0.1-1	--	--
	91 (200)	4.0	7.3	0.1-1	--	--
	136 (300)	6.0	7.2	0.1-1	--	--
	182 (400)	7.8	7.2	0.1-1	--	--
	227 (500)	9.6	7.2	0.1-1	--	--
	272 (600)	11.0	7.1	0.1-1	--	--
	318 (700)	12.9	7.1	0.1-1	--	--
	363 (800)	14.8	7.0	0.1-1	--	--
	408 (900)	17.0	7.0	0.1-1	--	--
	454 (1000)	19.2	6.9	0.1-1	--	--

[a] -- Not determined.

Table V (continued). EFFECT OF MILL CHLORINATION ON BACTERIAL MOTILITY AND ON COLIFORM CONCENTRATIONS

Date (1972)	Cl added		Eff. pH	Motile spirilla per field	Colif./100 ml X 10^5	Colif. redn., %
	Kg/day (#/day)	ppm				
May 25	0	0	6.9	1-10	550	0
	45 (100)	2.2	6.9	0.1-1	>1	--[a]
	68 (150)	3.2	6.8	0.1-1	>1	--
	91 (200)	4.2	6.8	0.1-1	>1	--
	113 (250)	5.2	6.8	1-10	>1	--
	136 (300)	6.2	6.7	1-10	>1	--
	182 (400)	8.2	6.7	1-10	>1	--
	227 (500)	10.2	6.6	0.1-1	>1	--
	272 (600)	12.5	6.6	1-10	>1	--
	318 (700)	14.5	6.5	0.1-1	>1	--
	454 (1000)	20.4	6.3	0	>1	--
May 26	0	0	6.8	0	--	--
	91 (200)	4.1	6.7	1-10	--	--
	136 (300)	6.2	6.7	1-10	--	--
	182 (400)	8.3	6.6	1-10	--	--
	227 (500)	10.6	6.6	1-10	--	--
	272 (600)	13.1	6.5	1-10	--	--
	318 (700)	15.8	6.4	1-10	--	--
	363 (800)	18.2	6.4	1-10	--	--
	408 (900)	20.6	6.3	1-10	--	--
	454 (1000)	23.5	6.2	0.1-1	--	--

[a] -- Not determined.

Table VI. EFFECT OF CAUSTIC ADDITION ON ACTIVITY OF CHLORINE IN MILL SYSTEM

Date (1972)	Additions to effluent			Eff. pH	Cl resid., ppm @		Motile sp./field @ 2 hrs	Colif./100 ml @ 2 hrs. X 10^5	Colif. redn., %
	NaOH	Chlorine							
	Kg/day (#/day)	Kg/day (#/day)	ppm		5 Min	2 Hr			
	0	0	0	--[a]	0	0	1-10	550	--
	0	45 (100)	2.2	--	0	0	0.1-1	> 1	< 99.818
	0	68 (150)	3.2	--	0	0	0.1-1	>1	< 99.818
	0	91 (200)	4.2	--	0	0	0.1-1	>1	< 99.818
	0	113 (250)	5.2	--	0	0	1-10	>1	<99.818
	0	136 (300)	6.2	--	0.69	0	1-10	>1	<99.818
	0	182 (400)	8.2	--	0.69	0	1-10	>1	<99.818
	0	227 (500)	10.2	--	1.1	0	0.1-1	>1	<99.818
	0	272 (600)	12.5	--	1.4	0	1-10	>1	<99.818
	0	318 (700)	14.5	--	1.4	0	0.1-1	>1	< 99.818
May 25	0	454 (1000)	20.4	--	2.7	0.86	0	>1	<99.818
	131 (288)	0	0	--	0	0	1-10	550	--
	131 (288)	45 (100)	2.1	--	0	0	0.1-1	> 1	< 99.818
	131 (288)	68 (150)	3.2	--	0	0	0.1-1	> 1	< 99.818
	131 (288)	91 (200)	4.5	--	0.78	0	0	0.034	99.994
	131 (288)	113 (250)	5.7	--	1.4	0	0	0.001	>99.999
	131 (288)	136 (300)	6.8	--	1.6	0	0	0.001	>99.999
	131 (288)	182 (400)	9.1	--	3.1	0.9	0	< 0.001	>99.999
	131 (288)	227 (500)	11.1	--	5.9	1.0	0	< 0.001	>99.999
	131 (288)	272 (600)	13.0	--	6.5	2.4	0	< 0.001	>99.999
	131 (288)	318 (700)	15.2	--	5.6	2.4	0	< 0.001	>99.999

[a] -- Not determined.

Table VI (continued). EFFECT OF CAUSTIC ADDITION ON ACTIVITY OF CHLORINE IN MILL SYSTEM

Date (1972)	Additions to effluent			Eff pH	Cl resid, ppm @		Motile sp/field @ 2 hrs	Colif/100 ml @ 2 hrs X 10^5	Colif redn, %
	NaOH	Chlorine							
	Kg/day (#/day)	Kg/day (#/day)	ppm		5 Min	2 Hr			
	0	0	0	6.8	0	0	1-10	--[a]	--
	0	91 (200)	4.1	6.7	0	0	1-10	--	--
	0	136 (300)	6.2	6.7	0	0	1-10	--	--
	0	182 (400)	8.3	6.6	0	0	1-10	--	--
	0	227 (500)	10.6	6.6	0.43	0	1-10	--	--
	0	272 (600)	13.1	6.5	0.69	0	1-10	--	--
	0	318 (700)	15.8	6.4	0.95	0	1-10	--	--
	0	363 (800)	18.2	6.4	1.70	0	1-10	--	--
	0	408 (900)	20.6	6.3	2.00	0	0.1-1	--	--
May 26	0	454 (1000)	23.5	6.2	2.60	0.86	0.1-1	--	--
	0	0	0	6.9	0	0	1-10	--	--
	98 (216)	91 (200)	4.8	6.9	0	0	0.1-1	--	--
	98 (216)	136 (300)	7.0	6.8	1.70	0	0	--	--
	82 (180)	182 (400)	9.5	6.7	2.50	0	0	--	--
	98 (216)	227 (500)	12.1	6.8	5.30	2.00	0	--	--
	114 (252)	272 (600)	14.6	6.7	5.80	2.00	0	--	--
	114 (252)	318 (700)	16.7	6.7	4.50	1.60	0	--	--
	147 (324)	363 (800)	19.0	6.5	3.00	0	0.01-0.1	--	--
	65 (144)	408 (900)	21.3	6.5	3.10	0	0	--	--
	65 (144)	454 (1000)	23.5	6.4	--	--	0	--	--

[a] -- Not determined.

Table VI (continued). EFFECT OF CAUSTIC ADDITION ON ACTIVITY OF CHLORINE IN MILL SYSTEM

Date	Additions to effluent			Eff	Cl resid, ppm @		Motile	Colif/100 ml	Colif
	NaOH	Chlorine							
(1972)	Kg/day (#/day)	Kg/day (#/day)	ppm	pH	5 Min	2 Hr	sp/field @ 2 hrs	@ 2 hrs X 10^5	redn, %
	0	0	0	7.2	0	0	1-10	--[a]	--
	164 (360)	91 (200)	4.7	7.1	0	0	0.01-1	--	--
	164 (360)	136 (300)	7.0	7.0	1.40	0	0	--	--
	228 (504)	182 (400)	9.2	6.9	--	0	0	--	--
	98 (216)	227 (500)	11.1	6.8	5.10	0.69	0	--	--
	163 (360)	272 (600)	12.9	6.8	6.60	2.00	0	--	--
	131 (288)	318 (700)	14.8	6.8	6.20	2.80	0	--	--
	163 (360)	363 (800)	16.6	6.7	4.30	0.95	0	--	--
	228 (504)	408 (900)	18.5	6.5	4.10	2.00	0.01-0.1	--	--
May 26	129 (285)	454 (1000)	20.2	6.5	3.20	2.60	0	--	--
	0	0	0	6.9	0	--	--	--	--
	490 (1080)	0	0	7.7	0	--	--	--	--
	458 (1010)	91 (200)	3.6	7.5	0	--	--	--	--
	327 (720)	136 (300)	5.5	7.4	0	--	--	--	--
	458 (1010)	182 (400)	7.3	7.4	1.7	--	--	--	--
	392 (864)	227 (500)	9.3	7.2	2.6	--	--	--	--
	458 (1010)	272 (600)	10.8	7.2	3.1	--	--	--	--
	458 (1010)	318 (700)	12.8	7.1	4.3	--	--	--	--
	458 (1010)	363 (800)	14.3	7.0	6.0	--	--	--	--
	458 (1010)	408 (900)	16.1	6.9	4.7	--	--	--	--
	458 (1010)	454 (1000)	17.7	6.8	6.1	--	--	--	--
	0	454 (1000)	17.6	6.4	1.9	--	--	--	--

[a] -- Not determined.

Table VI (continued). EFFECT OF CAUSTIC ADDITION ON ACTIVITY OF CHLORINE IN MILL SYSTEM

Date	Additions to effluent			Eff	Cl resid, ppm @		Motile	Colif/100 ml	Colif
	NaOH	Chlorine					sp/field	@ 2 hrs	redn,
(1972)	Kg/day (#/day)	Kg/day (#/day)	ppm	pH	5 Min	2 Hr	@ 2 hrs	X 10^5	%
June 29	0	0	0	7.2	0	0	1-10	310	--[a]
	11 (< 24)	91 (200)	5.0	--	0.43	0	0.01-0.1	29	90.645
	11 (< 24)	91 (200)	4.8	--	0.86	0	0.01-0.1	2.2	99.290
	11 (24)	91 (200)	4.6	--	1.00	0	0.01-0.1	0.0024	>99.999
	11 (24)	91 (200)	4.2	--	1.40	0	0	0.0018	>99.999
	19 (42)	91 (200)	3.9	--	1.50	0	0	0.0002	>99.999
	24 (54)	91 (200)	4.0	--	1.50	0	0	0.0001	>99.999
	47 (103)	91 (200)	4.4	--	1.30	0	0	0.0014	>99.999
July 20	0	0	0	6.4	0	0	1-10	26	--
	0	91 (200)	4.1	--	0	0	1-10	15	42.308
	0	136 (300)	6.5	--	0.69	0	1-10	10	61.538
	0	181 (400)	9.1	--	1.70	0.69	1-10	26	0
	98 (216)	91 (200)	3.9	--	1.50	0	0.01-0.1	0.001	99.996
	98 (216)	113 (250)	4.8	--	2.60	0	0.01-0.1	0.002	99.992
	98 (216)	136 (300)	5.6	--	2.70	0	0	0.001	99.996
	98 (216)	159 (350)	6.2	--	2.30	0	0.01-0.1	0.002	99.992
	131 (288)	159 (350)	6.2	--	2.80	1.21	0	0.003	99.988
July 21	0	0	0	6.6	0	0	1-10	21	--
	0	181 (400)	7.5	6.2	0.43	0	1-10	21	0
	0	227 (500)	9.3	6.2	1.30	0.86	1-10	22	0
	0	272 (600)	11.1	6.1	1.50	1.30	1-10	20	4.762
	0	318 (700)	12.7	6.0	2.20	1.70	0.1-1	2.2	89.524
	0	363 (800)	14.3	5.9	2.60	1.70	0.1-1	0.3	98.571
	0	408 (900)	16.4	5.8	3.20	1.70	0.01-0.1	0.035	99.833
	0	454 (1000)	17.5	5.8	3.90	2.20	0.01-0.1	0.01	99.952
	98 (216)	113 (250)	5.0	6.6	1.21	0.52	0	0.001	99.995

[a] -- Not determined.

Table VII. EFFECT OF AMMONIA ADDITION ON CHLORINE ACTIVITY IN MILL SYSTEM

Date	Chlorine addition			Ammonia addition			Eff	Chlorine resid, ppm		Motile sp/field
(1972)	Kg/day	(#/day)	ppm	Kg/day	(#/day)	% of req[a]	pH	5 Min	Hr	@ 2 hr
	0		0	0		0	6.8	0	0	--[b]
	227	(500)	10.4	0		0	6.6	0	0	--
	250	(550)	11.4	0		0	6.6	0	0	--
	272	(600)	12.5	0		0	6.6	0.86	0	--
	295	(650)	13.8	0		0	6.6	0.43	0	--
	318	(700)	15.2	0		0	6.5	0.86	0	--
	363	(800)	17.6	0		0	6.4	1.30	0	--
	408	(900)	20.0	0		0	6.4	1.40	0.43	--
May 16	454	(1000)	22.4	0		0	6.4	1.90	0.95	--
	0		--	0		--	6.7	0	0	--
	0		--	21	(47)	--	6.8	0	0	--
	113	(250)	5.7	21	(47)	78	6.8	0	0	--
	136	(300)	6.8	21	(47)	65	6.6	0.43	0	--
	182	(400)	8.9	21	(47)	49	6.6	0.86	0	--
	182	(400)	8.0	65	(144)	148	6.8	1.00	0	--
	227	(500)	10.0	65	(144)	118	6.8	1.00	0	--
	272	(600)	11.7	65	(144)	99	6.6	1.40	0.86	--
	318	(700)	13.7	65	(144)	85	6.6	1.40	0.86	--
	363	(800)	15.4	65	(144)	74	6.5	2.00	0.86	--
	408	(900)	17.3	65	(144)	66	6.4	2.40	1.30	--
	454	(1000)	19.6	65	(144)	59	6.4	2.40	--	--

[a] Percent of the NH_4^+ required to neutralize the HCl produced from the hydrolysis of Cl_2.

[b] -- Not determined.

Table VII(continued). EFFECT OF AMMONIA ADDITION ON CHLORINE ACTIVITY IN MILL SYSTEM

Date	Chlorine addition		Ammonia addition		Eff	Chlorine resid, ppm		Motile sp/field
(1972)	Kg/day (#/day)	ppm	Kg/day (#/day)	% of req[a]	pH	5 Min	Hr	@ 2 hr
	0	0	0	0	6.7	--[b]	--	0.1-1.0
	182 (400)	8.1	0	0	6.4	--	--	0.1-1.0
	227 (500)	9.9	0	0	6.3	--	--	0.1-1.0
	272 (600)	12.0	0	0	6.3	--	--	0.1-1.0
	318 (700)	14.0	0	0	6.3	--	--	0.1-1.0
	363 (800)	16.7	0	0	6.3	--	--	0.1-1.0
	408 (900)	19.1	0	0	6.2	--	--	0
May 17	454 (1000)	21.2	0	0	6.2	--	--	0.01-0.1
	0	0	0	0	6.7	--	0	0.1-1.0
	136 (300)	6.5	87 (192)	264	6.7	--	0	0.1-1.0
	182 (400)	8.7	87 (192)	197	6.6	--	0	0.1-1.0
	227 (500)	10.8	87 (192)	158	6.5	--	0	0.1-1.0
	272 (600)	12.5	87 (192)	132	6.5	--	0	0.1-1.0
	318 (700)	15.2	87 (192)	113	6.4	--	0	0.01-0.10
	363 (800)	18.2	87 (192)	99	6.3	--	0	0

[a] Percent of the NH_4^+ required to neutralize the HCl produced from the hydrolysis of Cl_2.

[b] -- Not determined.

Table VII(continued). EFFECT OF AMMONIA ADDITION ON CHLORINE ACTIVITY IN MILL SYSTEM

Date (1972)	Chlorine addition		Ammonia addition		Eff pH	Chlorine resid, ppm		Motile sp/field @ 2 hr
	Kg/day (#/day)	ppm	Kg/day (#/day)	% of req[a]		5 Min	Hr	
May 18	0	0	0	0	6.6	--[b]	0	0.1-1.0
	91 (200)	4.1	0	0	6.5	--	0	0.1-1.0
	136 (300)	6.2	0	0	6.5	--	0	0.1-1.0
	182 (400)	8.2	0	0	6.5	--	0	0.1-1.0
	227 (500)	10.5	0	0	6.4	--	0	0.1-1.0
	272 (600)	12.8	0	0	6.3	--	0	0.1-1.0
	318 (700)	14.9	0	0	6.2	--	0	0.1-1.0
	363 (800)	17.0	0	0	6.2	--	0	0.1-1.0
	408 (900)	19.2	0	0	6.1	--	0	0.1-1.0
	454 (1000)	21.2	0	0	6.1	--	0	0.1-1.0
	0	0	92 (202)	--	6.8	--	0	0.1-1.0
	91 (200)	3.9	92 (202)	415	6.7	--	0	0.1-1.0
	136 (300)	5.8	92 (202)	277	6.6	--	0	0.1-1.0
	182 (400)	7.2	92 (202)	208	6.5	--	0	0.1-1.0
	227 (500)	9.1	92 (202)	166	6.5	--	0	0.1-1.0
	136 (300)	6.5	65 (144)	197	6.6	--	0	0.1-1.0
	182 (400)	8.6	65 (144)	148	6.6	--	0	0.1-1.0
	227 (500)	10.4	65 (144)	118	6.5	--	0.42	0.1-1.0
	272 (600)	12.5	65 (144)	99	6.4	--	0.42	0.1-1.0
	363 (800)	16.3	65 (144)	74	6.4	--	0.42	0

[a] Percent of the NH_4^+ required to neutralize the HCl produced from the hydrolysis of Cl_2.
[b] -- Not determined.

Table VII(continued). EFFECT OF AMMONIA ADDITION ON CHLORINE ACTIVITY IN MILL SYSTEM

Date (1972)	Chlorine addition		Ammonia addition		Eff pH	Chlorine resid, ppm		Motile sp/field @ 2 hr
	Kg/day (#/day)	ppm	Kg/day (#/day)	% of req[a]		5 Min	Hr	
May 19	0	0	0	0	7.4	0	0	0.1-1.0
	91 (200)	4.0	0	0	7.3	0	0	0.1-1.0
	136 (300)	6.0	0	0	7.2	0	0	0.1-1.0
	182 (400)	7.8	0	0	7.2	0	0	0.1-1.0
	227 (500)	9.6	0	0	7.2	--[b]	--	0.1-1.0
	272 (600)	11.0	0	0	7.1	0.86	0	0.1-1.0
	318 (700)	12.9	0	0	7.1	1.3	0	0.1-1.0
	363 (800)	14.8	0	0	7.0	1.3	0	0.1-1.0
	408 (900)	17.0	0	0	7.0	1.7	0	0.1-1.0
	454 (1000)	19.2	0	0	6.9	1.7	0.43	0.1-1.0
	0	0	93 (204)	--	7.3	0	0	0.1-1.0
	91 (200)	4.4	93 (204)	420	7.5	0.86	0	0.1-1.0
	136 (300)	6.6	93 (204)	280	7.4	1.30	0	0.1-1.0
	182 (400)	9.0	93 (204)	210	7.4	1.70	0	0.1-1.0
	227 (500)	11.5	93 (204)	168	7.3	3.00	0	0.1-1.0
	272 (600)	13.8	93 (204)	140	7.2	2.60	0.43	0.1-1.0
	318 (700)	16.5	93 (204)	120	7.2	3.40	0.43	0
	363 (800)	18.6	93 (204)	105	7.1	3.40	0.43	0
	408 (900)	19.8	93 (204)	93	7.1	3.90	0.86	0
	454 (1000)	21.7	93 (204)	84	7.0	4.30	0.86	0

[a] Percent of the NH_4^+ required to neutralize the HCl produced from the hydrolysis of Cl_2.

[b] -- Not determined.

Table VIII. RESULTS FROM MONITORING OF FULL SCALE CHLORINATION

Date	Additives					Effluent flow		pH			Inject. H_2O press.		Motile sp/field	Total resid Cl, ppm[a]	
	Chlorine			NaOH (100%)				Inj	Effluent						
(1972)	Kg/day	(#/day)	ppm	Kg/day	(#/day)	L/sec	(TGH)	H_2O	Ini	Fin	kg/cm^2	($\#/in^2$)	@ 2 hrs	5 Min	2 Hr
July 18	113	(250)	4.9	133	(288)	268	(255)	12.1	--[b]	--	4.9	(70)	0	+	0
19	113	(250)	6.1	133	(288)	215	(205)	12.1	--	6.6	4.2	(60)	0	+	0
20	113	(250)	4.8	98	(216)	273	(260)	11.8	6.4	6.4	4.9	(70)	0.01-0.10	2.6	0
21	113	(250)	5.0	98	(216)	262	(250)	11.8	6.6	6.6	4.9	(70)	0	1.2	0.5
22	113	(250)	4.3	82	(180)	304	(290)	11.8	6.6	6.6	4.9	(70)	0	+	0
23	113	(250)	5.0	98	(216)	262	(250)	11.8	6.6	6.7	4.9	(70)	0	+	0
24	113	(250)	5.0	98	(216)	262	(250)	11.8	6.8	6.8	4.9	(70)	0	+	0
25	113	(250)	5.2	114	(252)	250	(240)	11.8	6.9	7.1	4.9	(70)	0	2.1	0
26	113	(250)	6.1	133	(288)	215	(205)	11.8	7.0	--	4.9	(70)	--	--	--
27	113	(250)	10.0	98	(216)	131	(125)	11.7	--	--	4.9	(70)	0	--	1.2
27	113	(250)	6.6	82	(180)	200	(190)	11.7	--	--	4.9	(70)	0	3.0	0
28	113	(250)	6.1	98	(216)	215	(205)	12.0	--	--	4.9	(70)	0	2.0	0
31	113	(250)	6.0	73	(162)	220	(210)	11.9	6.8	6.7	4.2	(60)	0	2.8	1.2
Aug. 2	113	(250)	6.1	82	(180)	215	(205)	12.1	--	6.8	5.1	(72)	0	3.3	0.7
3	113	(250)	6.0	82	(180)	220	(210)	12.2	6.8	6.9	4.6	(65)	0	1.8	0.7
4	113	(250)	5.1	82	(180)	257	(245)	12.1	6.9	7.0	4.8	(68)	0	1.1	0
7	113	(250)	4.2	90	(198)	315	(300)	12.4	6.8	6.9	1.1	(15)	0	1.0	0
7	113	(250)	5.4	90	(198)	242	(230)	11.9	--	--	4.9	(70)	0	2.1	0
8	113	(250)	5.8	98	(216)	226	(215)	11.9	6.8	6.9	4.2	(60)	--	2.4	--
9	113	(250)	6.4	82	(180)	205	(195)	11.9	6.7	6.8	4.9	(70)	0	2.0	0.5
10	113	(250)	6.4	82	(180)	205	(195)	11.9	6.7	6.8	5.1	(72)	0	2.0	0.5
11	113	(250)	5.4	82	(180)	242	(230)	11.9	6.7	6.8	4.9	(70)	0	2.2	0
14	113	(250)	5.3	82	(180)	247	(235)	12.1	7.3	7.3	4.9	(70)	0	2.7	0
15	113	(250)	5.4	82	(180)	242	(230)	12.1	7.3	7.2	4.9	(70)	0	2.2	0

[a] + = Residual present but concentration not determined.
[b] -- Not determined.

Table VIII (continued). RESULTS FROM MONITORING OF FULL SCALE CHLORINATION

Date	Additives					Effluent flow		pH			Inject. H_2O press.		Motile sp/field	Total resid Cl, ppm[a]	
	Chlorine			NaOH (100%)				Inj	Effluent						
(1972)	Kg/day	(#/day)	ppm	Kg/day	(#/day)	L/sec	(TGH)	H_2O	Ini	Fin	kg/cm^2	(#/in^2)	@ 2 hrs	5 Min	2 Hr
Aug. 16	113	(250)	4.7	82	(180)	278	(265)	11.9	6.7	6.8	4.9	(70)	0	2.1	0
17	113	(250)	7.6	82	(180)	173	(165)	12.1	--[b]	7.2	4.9	(70)	0	3.8	1.6
17	113	(250)	6.1	82	(180)	215	(205)	12.1	7.2	7.2	4.9	(70)	0	3.2	0.3
18	113	(250)	6.0	82	(180)	220	(210)	11.9	--	--	4.6	(65)	0	2.8	0
20	113	(250)	5.6	82	(180)	236	(225)	--	--	--	4.6	(65)	0	4.0	1.0
22	113	(250)	5.4	82	(180)	242	(230)	11.9	7.3	7.3	4.6	(65)	0	2.7	0.3
23	113	(250)	6.0	82	(162)	220	(210)	11.9	7.3	7.2	4.6	(65)	0	1.9	0
24	113	(250)	5.4	82	(180)	242	(230)	11.9	--	--	4.2	(60)	0	2.3	1.2
28	113	(250)	5.8	82	(180)	226	(215)	11.9	--	7.2	4.6	(65)	0	2.8	0
29	113	(250)	6.2	82	(180)	210	(200)	11.9	7.3	7.3	4.6	(65)	0	2.1	0
29	113	(250)	5.4	82	(180)	242	(230)	11.9	--	--	4.6	(65)	0	2.8	0
31	113	(250)	6.0	82	(180)	220	(210)	11.9	--	7.2	4.6	(65)	0	2.6	0
Sept. 8	113	(250)	5.3	180	(396)	247	(235)	12.1	--	7.0	3.0	(43)	0	2.4	0
14	113	(250)	5.4	24	(54)	242	(230)	11.3	--	7.0	3.2	(45)	0	2.1	1.5
14	113	(250)	5.4	33	(72)	242	(230)	11.7	--	7.0	3.2	(45)	0	2.7	1.9
14	113	(250)	5.4	139	(306)	242	(230)	13.2	--	7.6	1.6	(23)	0	3.6	2.2
15	113	(250)	5.3	65	(144)	247	(235)	12.2	--	7.0	3.2	(45)	0	2.6	2.2
17	.13	(250)	5.1	65	(144)	257	(245)	12.2	7.1	7.1	3.2	(45)	0	2.7	2.3
17	0	(0)	0	0	(0)	257	(245)	--	7.1	--	3.2	(45)	1.0-10.0	1.7	1.6
19	113	(250)	4.6	65	(144)	284	(270)	12.2	7.0	7.0	3.5	(50)	0	2.7	2.0
19	0	(0)	0	0	(0)	284	(270)	--	7.0	--	3.5	(50)	1.0-10.0	2.0	2.2
20	113	(250)	4.8	65	(144)	273	(260)	12.2	7.1	7.1	3.4	(48)	0	2.1	1.4
20	0	(0)	0	0	(0)	273	(260)	--	7.1	--	3.4	(48)	1.0-10.0	1.3	1.2

[a] + = Residual present but concentration not determined.

[b] -- Not determined.

Table VIII (continued). RESULTS FROM MONITORING OF FULL SCALE CHLORINATION

Date (1972)	Additives					Effluent flow		pH			Inject. H_2O press.		Motile sp/field @ 2 hrs	Total resid Cl, ppm[a]	
	Chlorine			NaOH (100%)				Inj H_2O	Effluent						
	Kg/day	(#/day)	ppm	Kg/day	(#/day)	L/sec	(TGH)		Ini	Fin	kg/cm^2	(#/in.^{2})		5 Min	2 Hr
Sept. 22	113	(250)	10.0	71	(156)	131	(125)	12.3	7.0	7.0	3.4	(48)	0	6.4	2.9
22	0	(0)	0	0	(0)	131	(125)	--[b]	7.0	--	3.4	(48)	1.0-10.0	0	0
26	113	(250)	6.2	65	(144)	210	(200)	12.2	7.0	7.0	3.0	(43)	0	2.7	1.3
26	0	(0)	0	0	(0)	210	(200)	--	7.0	--	3.0	(43)	1.0-10.0	1.7	0.9
29	113	(250)	5.4	--	(--)	242	(230)	12.1	6.9	7.0	3.2	(45)	0	1.6	0.7
29	0	(0)	0	0	(0)	242	(230)	--	6.9	--	3.2	(45)	1.0-10.0	0	0
Oct. 2	113	(250)	5.2	59	(130)	252	(240)	12.1	6.9	6.9	3.0	(42)	0	2.3	0.7
2	0	(0)	0	0	(0)	252	(240)	--	6.9	--	3.0	(42)	0.1-1.0	1.6	1.0
5	113	(250)	6.4	72	(158)	205	(195)	12.2	7.0	7.0	3.2	(46)	0	2.1	0.8
5	0	(0)	0	0	(0)	205	(195)	--	7.0	--	3.2	(46)	0.1-1.0	0	0
7	113	(250)	6.0	59	(130)	217	(207)	12.2	7.0	7.0	3.2	(45)	0	2.4	0.7
7	0	(0)	0	0	(0)	217	(207)	--	7.0	--	3.2	(45)	0.1-1.0	0	0
9	113	(250)	5.2	65	(144)	252	(240)	12.2	7.0	7.0	2.8	(40)	0	2.0	0.3
9	0	(0)	0	0	(0)	252	(240)	--	7.0	--	2.8	(40)	1.0-10.0	0	0
10	113	(250)	6.4	59	(130)	205	(195)	12.3	7.2	7.2	2.8	(40)	0	2.6	0.7
10	0	(0)	0	0	(0)	205	(195)	--	7.2	--	2.8	(40)	1.0-10.0	0	0
11	113	(250)	5.8	65	(144)	226	(215)	12.3	7.0	7.0	3.0	(43)	0	2.1	0
11	0	(0)	0	0	(0)	226	(215)	--	7.0	--	3.0	(43)	1.0-10.0	0	0
13	113	(250)	6.0	72	(158)	220	(210)	12.2	6.9	7.0	2.8	(40)	0	1.6	0
13	0	(0)	0	0	(0)	220	(210)	--	6.9	--	2.8	(40)	1.0-10.0	0	0
16	113	(250)	6.6	65	(144)	200	(190)	12.3	6.9	7.1	2.8	(40)	0	1.6	0
16	0	(0)	0	0	(0)	200	(190)	--	6.9	--	2.8	(40)	1.0-10.0	0	0
17	113	(250)	6.2	59	(130)	210	(200)	12.2	7.1	7.1	2.8	(40)	0	1.6	0
17	0	(0)	0	0	(0)	210	(200)	--	7.1	--	2.8	(40)	1.0-10.0	0	0

[a]+ = Residual present but concentration not determined.
b -- Not determined.

Table VIII (continued). RESULTS FROM MONITORING OF FULL SCALE CHLORINATION

Date	Additives					Effluent flow		pH			Inject. H_2O press.		Motile sp/field	Total resid Cl, ppm[a]	
	Chlorine			NaOH (100%)				Inj	Effluent						
(1972)	Kg/day	(#/day)	ppm	Kg/day	(#/day)	L/sec	(TGH)	H_2O	Ini	Fin	kg/cm^2	(#/in^2)	@ 2 hrs	5 Min	2 Hr
Oct. 18	113	(250)	6.0	33	(72)	220	(210)	12.0	7.1	7.1	2.8	(40)	0	1.7	0
18	0	(0)	0	0	(0)	220	(210)	--[b]	7.1	--	2.8	(40)	1.0-10.0	0	0
19	113	(250)	5.7	59	(130)	231	(220)	12.2	7.0	7.0	2.8	(40)	0	1.6	0
19	0	(0)	0	0	(0)	231	(220)	--	7.0	--	2.8	(40)	1.0-10.0	0	0
23	113	(250)	6.8	--	(--)	194	(185)	12.2	7.0	7.0	2.8	(40)	0	1.7	0
23	0	(0)	0	0	(0)	194	(185)	--	7.0	--	2.8	(40)	1.0-10.0	0	0
25	113	(250)	6.0	78	(173)	220	(210)	12.4	7.0	7.0	2.8	(40)	0	1.7	0
25	0	(0)	0	0	(0)	220	(210)	--	7.0	--	2.8	(40)	1.0-10.0	0	0
27	113	(250)	5.7	72	(159)	231	(220)	12.2	7.0	7.0	3.4	(48)	0	1.6	0
27	0	(0)	0	0	(0)	231	(220)	--	7.0	--	3.4	(48)	1.0-10.0	0	0
31	113	(250)	5.8	72	(159)	226	(215)	12.4	7.0	7.0	3.2	(45)	0	2.9	0
31	0	(0)	0	0	(0)	226	(215)	--	7.0	--	3.2	(45)	1.0-10.0	0	0
Nov. 1	113	(250)	5.6	72	(159)	236	(225)	12.4	7.0	7.0	2.8	(40)	0	1.7	0
1	0	(0)	0	0	(0)	236	(225)	--	7.0	--	2.8	(40)	0.1-1.0	0	0
6	113	(250)	6.4	65	(143)	205	(195)	12.2	6.8	6.8	2.8	(40)	0	2.4	0
6	0	(0)	0	0	(0)	205	(195)	--	6.8	--	2.8	(40)	1.0-10.0	0	0
8	113	(250)	6.9	72	(159)	189	(180)	12.4	6.8	6.8	2.6	(37)	0	2.4	0
8	0	(0)	0	0	(0)	189	(180)	--	6.8	--	2.6	(37)	0.1-1.0	0	0
9	113	(250)	6.1	69	(151)	215	(205)	12.3	6.7	6.8	2.6	(37)	0	1.9	0
9	0	(0)	0	0	(0)	215	(205)	--	6.7	--	2.6	(37)	0.1-1.0	0	0
13	113	(250)	7.1	--	(--)	184	(175)	12-13	6.9	7.6	2.6	(37)	0	3.0	0
13	0	(0)	0	0	(0)	184	(175)	--	6.9	--	2.6	(37)	1.0-10.0	0	0

[a] + = Residual present but concentration not determined.

[b] -- Not determined.

Table VIII (continued). RESULTS FROM MONITORING OF FULL SCALE CHLORINATION

Date	Additives					Effluent flow		pH			Inject. H_2O press.		Motile sp/field	Total resid Cl, ppm[a]	
	Chlorine			NaOH (100%)				Inj	Effluent						
(1972)	Kg/day	(#/day)	ppm	Kg/day	(#/day)	L/sec	(TGH)	H_2O	Ini	Fin	kg/cm^2	(#/in^2)	@ 2 hrs	5 Min	2 Hr
Nov. 13	113	(250)	7.1	--	(--)	184	(175)	12-13	6.6	7.7	2.6	(37)	0	2.7	0.6
13	0	(0)	0	0	(0)	184	(175)	--	6.6	--	2.6	(37)	0.1-1.0	0	0
16	113	(250)	6.0	72	(159)	220	(210)	12.5	7.0	7.1	2.4	(34)	0	2.4	0.6
16	0	(0)	0	0	(0)	220	(210)	--	7.0	--	2.4	(34)	1.0-10.0	0	0
25	113	(250)	6.8	72	(159)	194	(185)	12.9	7.0	7.2	1.4	(20)	0	1.8	0
25	0	(0)	0	0	(0)	194	(185)	--	7.0	--	1.4	(20)	1.0-10.0	0	0
Mean	113	(250)	5.9	81	(178)	228	(217)	12.1	6.9	7.0	3.8	(54)	<0.01	2.4	1.4
S.D.	0		1.0	30	(66)	33	(31)	0.3	0.2	0.2	1.1	(15)	<0.001	0.8	1.1
Var., %	0		17	37		14		--	--	--	28		<0.1	33	79
# of Samp	70		70	66		70		70	50	50	70		70	63	63

[a] + = Residual present but concentration not determined.

[b] -- Not determined.

Table IX. EFFECT OF CHLORINATION ON RECEIVING WATERS

Analysis and sample point[a]	Unchlorinated effluent					Chlorinated eff		No Cl
	June (1972)					June (1972)		July
	12	13	15	20	27	28	30	7
pH								
Cement plant	--[b]	--	--	--	--	--	--	7.2
M.S. bridge	6.9	6.9	6.3	6.4	7.3	7.2	6.7	6.4
M.S. mouth	7.1	6.9	6.4	6.8	7.4	6.9	4.8	6.4
Pipe xng.	--	--	--	--	--	7.0	--	7.1
Sand. Bridge	--	--	--	--	--	--	--	--
D.O.--ppm								
Cement plant	--	--	--	--	--	--	--	--
M.S. bridge	6.5	6.3	3.6	6.9	--	--	--	--
M.S. mouth	2.6	1.4	0.4	5.4	--	--	--	--
Pipe xng.	--	--	--	--	--	--	--	--
Sand. bridge	--	--	--	--	--	--	--	--
Temp.--°C								
Cement plant	--	--	--	--	--	--	--	16.5
M.S. bridge	18.6	20.4	25.0	21.0	18.8	21.0	27.0	22.0
M.S. mouth	22.5	22.8	24.3	21.3	20.4	24.5	29.2	22.0
Pipe xng.	--	--	--	--	--	18.8	--	16.8
Sand. bridge	--	--	--	--	--	--	--	--
Cl resid.--ppm								
Cement plant	--	--	--	--	--	--	--	--
M.S. bridge	0	0	0	0	0	--	--	--
M.S. mouth	0	0	0	0	0	--	--	--
Pipe xng.	--	--	--	--	--	--	--	--
Sand. bridge	--	--	--	--	--	--	--	--
Coliforms/100 ml --Log_{10}								
Cement plant	--	--	--	--	--	--	--	2.11
M.S. bridge	6.60	6.48	6.78	6.70	7.15	4.48	6.04	6.32
M.S. mouth	6.46	6.20	6.85	6.23	7.04	5.18	5.00	6.12
Pipe xng.	--	--	--	--	--	3.56	--	4.36
Sand. bridge	--	--	--	--	--	--	--	--

[a] See last page of table.

[b] -- Not determined.

Table IX (continued). EFFECT OF CHLORINATION ON RECEIVING WATERS

Analysis and sample point[a]	Chlorinated effluent							
	July (1972)							Aug.
	8	18	19	21	25	27	31	3
pH								
Cement plant	7.4	7.1	--[b]	8.2	7.4	7.7	7.6	7.4
M.S. bridge	6.7	7.3	--	7.0	7.3	7.0	7.3	7.3
M.S. mouth	6.6	7.0	--	7.2	7.2	7.7	7.1	7.0
Pipe xng.	7.2	7.1	--	8.2	7.2	7.0	7.4	7.4
Sand. bridge	--	7.5	--	8.1	7.2	6.9	7.2	7.2
D.O.--ppm								
Cement plant	--	10.0	10.4	10.3	10.5	10.6	10.9	10.0
M.S. bridge	--	5.8	6.5	4.7	9.0	7.6	7.0	7.5
M.S. mouth	--	1.2	0.9	3.7	6.0	0.4	3.0	3.5
Pipe xng.	--	7.7	4.9	9.1	8.6	8.4	9.3	9.5
Sand. bridge	--	10.2	9.0	8.9	8.4	8.2	9.1	9.4
Temp.--°C.								
Cement plant	16.0	20.6	21.0	20.6	16.3	18.0	20.8	20.0
M.S. bridge	22.0	25.6	24.8	25.0	18.0	21.0	24.0	23.0
M.S. mouth	21.8	24.8	27.8	23.6	18.0	26.5	24.0	24.0
Pipe xng.	16.5	22.0	20.8	20.6	17.6	18.5	20.4	19.0
Sand. bridge	--	23.7	23.9	22.8	18.0	21.5	21.9	21.0
Cl resid.--ppm								
Cement plant	--	--	--	1.7	1.3	1.2	0.5	3.6
M.S. bridge	--	--	--	0.9	0	0	0	1.0
M.S. mouth	--	0	0	1.1	0	0	0	0.3
Pipe xng.	--	--	--	1.2	0.5	0.7	0.5	0.7
Sand. bridge	--	--	--	0.7	0.5	0.7	0.4	1.1
Coliforms/100 ml --$\log_{10}$								
Cement plant	2.15	2.00	2.20	1.48	1.60	1.00	1.48	1.78
M.S. bridge	6.00	5.43	4.85	3.62	2.85	6.73	2.70	3.78
M.S. mouth	5.90	6.60	5.49	4.60	4.51	7.08	4.20	3.85
Pipe xng.	4.49	4.72	4.28	3.84	2.90	4.23	2.70	2.70
Sand bridge	--	4.81	3.78	4.04	2.48	4.38	2.00	2.45

[a] See last page of table.

[b] -- Not determined.

Table IX (continued). EFFECT OF CHLORINATION ON RECEIVING WATERS

Analysis and sample point[a]	Chlorinated effluent							
	August (1972)							
	8	11	16	18	24	29	30	31
pH								
Cement plant	7.2	6.9	7.4	--[b]	7.1	--	7.7	7.9
M.S. bridge	7.0	6.8	7.2	7.2	7.6	--	--	--
M.S. mouth	6.8	6.9	7.2	7.4	7.3	--	7.2	7.4
Pipe xng.	7.1	7.0	7.3	--	7.1	--	7.6	7.9
Sand. bridge	7.1	7.0	7.3	7.5	7.1	--	7.6	7.8
D.O.--ppm								
Cement plant	9.9	10.8	11.4	--	10.4	--	--	--
M.S. bridge	5.0	7.6	7.0	9.0	7.1	--	--	--
M.S. mouth	1.3	5.2	3.3	7.1	1.5	--	--	--
Pipe xng.	8.6	10.8	10.8	--	9.6	--	--	--
Sand. bridge	8.2	10.8	10.8	10.6	9.3	--	--	--
Temp.--°C.								
Cement plant	23.0	15.6	15.8	--	13.7	--	--	--
M.S. bridge	26.4	19.9	20.0	16.0	19.9	--	--	--
M.S. mouth	29.4	19.6	18.8	15.6	18.4	--	--	--
Pipe xng.	23.8	16.0	16.8	--	14.7	--	--	--
Sand. bridge	24.8	17.0	17.0	15.6	14.9	--	--	--
Cl resid.--ppm								
Cement plant	0	0	0	--	0	--	--	--
M.S. bridge	0.8	0	0	0	0	--	--	--
M.S. mouth	0	0	0	0	0	--	--	--
Pipe xng.	0.9	0	0	--	0	--	--	--
Sand. bridge	1.6	0.4	0	0	0	--	--	--
Coliforms/100 ml --Log_{10}								
Cement plant	1.60	2.15	2.75	--	2.46	1.95	1.70	1.85
M.S. bridge	2.30	4.00	3.61	2.95	3.51	--	--	--
M.S. mouth	4.78	3.48	4.18	4.30	6.51	3.08	2.30	1.90
Pipe xng.	2.32	2.70	2.56	--	4.93	2.11	2.23	2.04
Sand. bridge	2.38	2.57	2.78	2.28	3.42	1.70	2.11	2.20

[a] Cement Plant--Upstream control.
Mark Slough (M.S.) Bridge--305 M (334 yd.) downstream.
M.S. Mouth--1.22 Km (1334 yd.) downstream of effluent discharge.
Pipeline Crossing (Pipe xng.)--4.83 Km (3 mi.) downstream.
Sandersons (Sand.) Bridge--12.9 Km (8 mi.) downstream.

[b] -- Not determined.

Table X. CONTINUOUS TOXICITY TEST WITH STEELHEAD TROUT. EXPERIMENT 1

Measurement and sampling point	Elapsed time, days				
	Start	1	2	3	4
Chlorine added, ppm	10	10-20[a]	Test was stopped after 1 day		
Fish killed, %					
Ch 1 Water control	0	0			
4 Unchlor eff, 67%	0	100			
5 Unchlor eff, 50%	0	0			
6 Chlor eff, 50%	0	100			
pH					
Ch 1	7.1	7.0			
4	6.9	7.1			
5	7.0	7.2			
6	7.1	7.3			
Temp, °C					
Ch 1	7.0	12.5			
4	7.1	19.1			
5	7.2	17.0			
6	7.3	17.0			
D.O., ppm					
Ch 1	11.8	10.8			
4	8.9	8.7			
5	10.0	9.4			
6	8.9	9.4			
Total resid Cl, ppm					
Chlor eff headbox	+[b]	--[c]			
Coliforms/100 ml					
Chlor eff headbox	1100	--			
Inh. of O_2 uptake, %					
Aging box	88	--			
Coliform reduction, %					
Aging box	99.997	--			

---

[a] A partially plugged effluent delivery tube caused high chlorine concentrations.

[b] Residual present but concentration not determined.

[c] -- Not determined.

Table XI. CONTINUOUS TOXICITY TEST WITH STEELHEAD TROUT. EXPERIMENT 2

Measurement and sampling point	Elapsed time, days				
	Start	1	2	3	4
Chlorine added, ppm	10	10	10	10	10
Fish killed, %					
Ch 1 Water control	0	0	0	0	0
2 Chlor eff, 5%	0	0	0	0	0
3 Chlor eff, 10%	0	0	0	10	30
4 Chlor eff, 20%	0	60	100	100	100
5 Chlor eff, 40%	0	100	100	100	100
6 Unchlor eff, 50%	0	70	100	100	100
pH					
Ch 1	--[a]	7.6	7.5	7.6	7.2
2	--	7.6	7.5	7.5	7.2
3	--	7.5	7.4	7.5	7.3
4	--	7.5	7.5	7.5	7.3
5	--	7.5	7.6	7.5	7.4
6	--	7.4	7.6	7.4	7.2
Temp, °C					
Ch 1	--	9.0	8.0	14.2	9.0
2	--	9.4	8.3	13.2	9.2
3	--	9.7	8.9	11.4	9.4
4	--	10.8	9.5	10.5	10.3
5	--	12.6	11.0	10.1	12.0
6	--	14.1	12.7	9.6	13.5
D.O., ppm					
Ch 1	--	11.6	12.1	10.2	12.1
2	--	11.6	11.9	10.4	11.9
3	--	11.5	11.8	10.8	11.6
4	--	11.2	11.6	11.2	11.4
5	--	10.6	11.2	11.5	10.9
6	--	10.0	10.8	11.8	10.2
Total resid Cl, ppm					
Chlor eff headbox	--	1.5	1.9	1.7	2.4
Coliforms/100 ml					
Chlor eff headbox	--	--	100	--	--
Inh of O_2 uptake, %					
Aging box	92	99	98	95	97
Coliform reduction, %					
Aging box	--	--	99.999	--	--

[a] -- Not determined.

Table XII. CONTINUOUS TOXICITY TEST WITH SOCKEYE SALMON
EXPERIMENT 3

Measurement and sampling point	Elapsed time, days				
	3.5 Hrs	1	2	3	4
Chlorine added, ppm	4.1	6.9	5.5	--[a]	--
Fish Killed, %					
Ch 1 Water control	0	0	0	--	--
2 Chlor eff, 5%	0	0	0	--	--
3 Chlor eff, 10%	0	0	0	--	--
4 Chlor eff, 20%	0	0	0	--	--
5 Chlor eff--unaged, 20%	25	100	100	--	--
pH					
Ch 1	7.6	7.1	7.0	--	--
2	7.5	7.0	7.0	--	--
3	7.4	6.9	6.9	--	--
4	7.1	6.7	6.8	--	--
5	7.0	7.0	--	--	--
Temp, °C					
Ch 1	17.1	17.8	18.1	--	--
2	17.5	18.0	18.4	--	--
3	18.0	18.3	18.8	--	--
4	19.0	20.0	21.0	--	--
5	19.0	20.0	--	--	--
D.O., ppm					
Ch 1 No readings taken	--	--	--	--	--
2 because of	--	--	--	--	--
3 defective probe.	--	--	--	--	--
4	--	--	--	--	--
5	--	--	--	--	--
Total resid Cl, ppm					
Chlor eff headbox	0	0	0	--	--
Coliforms/100 ml					
Chlor eff headbox	--	--	--	--	--
Inh of O_2 uptake, %					
Aging box	--	---	--	--	--
Coliform reduction, %					
Aging box	--	--	--	--	--

[a] -- Not determined.

Table XIII. CONTINUOUS TOXICITY TEST WITH SOCKEYE SALMON. EXPERIMENT 4

Measurement and sampling point	Elapsed time, days			
	1	2	3	4
Chlorine added, ppm	5.8	6.4	5.4	5.8
Fish killed, %				
Ch 1 Water control	0	0	0	0
2 Chlor eff, 5%	0	5	5	5
3 Chlor eff, 10%	0	0	0	0
4 Chlor eff, 20%	0	0	0	0
pH				
Ch 1	7.3	7.3	7.3	--[a]
2	7.2	7.3	7.3	--
3	7.2	7.3	7.3	--
4	7.2	7.3	7.3	--
Temp, °C				
Ch 1	20.7	18.7	17.8	--
2	20.7	18.7	17.9	--
3	20.8	18.9	18.2	--
4	21.4	19.8	19.2	--
D.O., ppm				
Ch 1	8.8	9.6	10.4	--
2	8.8	9.6	10.4	--
3	8.8	9.6	10.2	--
4	8.6	9.2	9.8	--
Total resid Cl, ppm				
Chlor eff headbox	0	0.5	0	--
Coliforms/100 ml				
Chlor eff headbox	--	--	∠100	--
Inh of O_2 uptake, %				
Aging box	90	91	88	--
Coliform reduction, %				
Aging box	--	--	99.999	--

[a] -- Not determined.

Table XIV. CONTINUOUS TOXICITY TEST WITH SOCKEYE SALMON. EXPERIMENT 5

Measurement and sampling point	Elapsed time, days				
	0.3	1	2	3	4
Chlorine added, ppm	4.4	4.5	4.7	6.3	6.0
Fish killed, %					
Ch 1 Water control	0	0	0	0	0
2 Chlor eff, 5%	0	0	0	0	0
3 Chlor eff, 10%	0	0	0	0	0
4 Chlor eff, 20%	0	0	0	5	5
pH					
Ch 1	7.7	7.6	--[a]	7.8	--
2	7.7	7.6	--	7.6	--
3	7.7	7.6	--	7.5	--
4	7.6	7.4	--	7.4	--
Temp, °C					
Ch 1	17.3	17.3	--	15.7	--
2	17.5	17.6	--	16.0	--
3	17.8	17.8	--	16.8	--
4	19.0	18.1	--	17.8	--
D.O., ppm					
Ch 1	--	--	--	10.4	--
2	--	--	--	10.4	--
3	--	--	--	10.2	--
4	--	--	--	9.3	--
Total resid Cl, ppm					
Chlor eff headbox	0	0	--	0.8	--
Coliforms/100 ml					
Chlor eff headbox	--	--	--	<100	--
Inh of O_2 uptake, %					
Aging Box	--	--	--	65	--
Coliform reduction, %					
Aging box	--	--	--	99.999	--

[a] -- Not determined.

Table XV. CONTINUOUS TOXICITY TEST WITH SOCKEYE SALMON. EXPERIMENT 6

Measurement and sampling point	Elapsed time, days				
	0.1	1	2	3	4
Chlorine added, ppm	3.9	--[a]	4.5	5.0	5.4
Fish killed, %					
Ch 1 Water control	0	0	0	0	0
2 Chlor eff, 5%	0	0	0	0	0
3 Chlor eff, 10%	0	0	0	0	0
4 Chlor eff, 20%	0	0	0	0	0
pH					
Ch 1	--	--	7.7	7.7	--
2	--	--	7.7	7.7	--
3	--	--	7.7	7.7	--
4	--	--	7.6	7.6	--
Temp, °C					
Ch 1	16.0	--	15.1	15.9	--
2	16.9	--	15.4	16.1	--
3	17.0	--	16.2	16.8	--
4	18.0	--	17.4	17.7	--
D.O., ppm					
Ch 1	11.0	--	10.9	10.9	--
2	11.0	--	10.9	10.9	--
3	10.6	--	10.7	10.6	--
4	10.2	--	10.1	10.0	--
Total resid Cl, ppm Chlor eff headbox	0	--	0.3	0	--
Coliforms/100 ml Chlor eff headbox	--	--	--	100	--
Inh of O_2 uptake, % Aging box	85	--	95	94	--
Coliform reduction, % Aging box	--	--	--	99.999	--

[a] -- Not determined.

Table XVI. CONTINUOUS TOXICITY TEST WITH SOCKEYE SALMON. EXPERIMENT 7

Measurement and sampling point	Elapsed time, days			
	1	2	3	4
Chlorine added, ppm	4.5	--[a]	5.0	--
Fish killed, %				
Ch 1 Water control	0	0	0	0
2 Chlor eff, 5%	0	0	0	0
3 Chlor eff, 10%	0	0	0	0
4 Chlor eff, 20%	0	0	0	0
pH				
Ch 1	7.9	--	7.6	--
2	7.9	--	7.6	--
3	7.8	--	7.6	--
4	7.8	--	7.5	--
Temp, °C				
Ch 1	16.0	--	14.7	--
2	17.2	--	15.8	--
3	17.4	--	16.0	--
4	18.2	--	16.8	--
D.O., ppm				
Ch 1	10.6	--	10.4	--
2	10.2	--	10.2	--
3	10.2	--	10.2	--
4	9.8	--	9.6	--
Total resid Cl, ppm				
Chlor eff headbox	0	--	0	--
Coliforms/100 ml				
Chlor eff headbox	--	--	210	--
Inh of O_2 uptake, %				
Aging box	88	--	90	--
Coliform reduction, %				
Aging box	--	--	99.999	--

[a] -- Not determined.

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